HANDBOOK ON
SMART/INTELLIGENT GRID SYSTEMS DEVELOPMENT AND DEPLOYMENT

Funded by:
The European Union (EU)

Prepared by:
World Alliance for Thai Decentralised Energy Association (WADE THAI)

Associate Partner:

Partner:
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<tr>
<td>AC</td>
<td>Alternating Current</td>
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<td>Alternative Energy Development Plan</td>
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<td>AES</td>
<td>Advanced Encryption Standard</td>
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<td>Automatic Generation Control</td>
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<td>AMI</td>
<td>Advanced Metering Infrastructure</td>
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<td>Association of Southeast Asian Nations</td>
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<td>Buddhist Era</td>
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<td>Broadband over Power Lines</td>
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<td>CFL</td>
<td>Compact Fluorescent Light</td>
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<td>International Council On Large Electric Systems</td>
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<td>Concentrating Solar Power</td>
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<td>Data Circuit-Terminating Equipment</td>
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<td>DoS</td>
<td>Denial of Service</td>
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<td>Digital Subscriber Line</td>
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<td>Energy Planning Management</td>
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<td>Energy Regulatory Commission of Thailand</td>
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<td>EV</td>
<td>Electric Vehicles</td>
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<td>FAN</td>
<td>Field Area Networks</td>
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<tr>
<td>FDIR</td>
<td>Fault Detection, Isolation and Restoration</td>
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<td>Federal Energy Regulatory Commission</td>
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<td>FHSS</td>
<td>Frequency Hopping Spread Spectrum</td>
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<td>Fault Location, Isolation and Service Restoration</td>
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<td>GHG</td>
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<td>GW</td>
<td>Gigawatt</td>
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<td>HAN</td>
<td>Home Area Network</td>
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<td>HEMS</td>
<td>Home Energy Management Systems</td>
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<td>HEV</td>
<td>Hybrid Electric Vehicle</td>
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<td>HVAC</td>
<td>Heating, Ventilation, and Air-Conditioning</td>
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<td>HVDC</td>
<td>High-Voltage, Direct Current</td>
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<td>IAN</td>
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<td>ICE</td>
<td>Internal Combustion Engine</td>
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<td>ICT</td>
<td>Information Communication Technology</td>
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<td>IEC</td>
<td>International Electrotechnical Commission</td>
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<td>IEDs</td>
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<td>IEEE PES</td>
<td>Institute of Electrical And Electronics Engineers-Power Engineering Society</td>
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<td>IRP</td>
<td>Integrated Resource Planning</td>
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<td>International Organisation for Standardisation</td>
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<td>Meter Data Management Systems</td>
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<td>MEA</td>
<td>Metropolitan Electricity Authority</td>
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<td>MSW</td>
<td>Municipal Solid Waste</td>
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<td>MW</td>
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<td>Organisation for Economic Co-operation and Development</td>
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<td>Power System Stabilisers</td>
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<td>Reliability Coordinators</td>
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<td>RD&amp;D</td>
<td>Research, Development and Demonstration</td>
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<td>RF</td>
<td>Radio Frequency</td>
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<td>Return on Investment</td>
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<td>RTP</td>
<td>Real Time Pricing</td>
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<td>SA</td>
<td>Substation Automation</td>
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<td>SAS</td>
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<td>Supervisory Control And Data Acquisition</td>
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<td>SE</td>
<td>State Estimator</td>
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<td>Transmission Control Protocol / Internet Protocol</td>
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<td>TOD</td>
<td>Time Of Day</td>
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<td>WAN</td>
<td>Wide Area Network</td>
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This Handbook on Smart/Intelligent Grid Systems Development and Deployment is a collaborative effort among the Partners of the “Smart/Intelligent Grid Development and Deployment in Thailand (Smart Thai)”, a project funded by the European Union. The World Alliance for Thai Decentralised Energy Association (WADE THAI), the Lead Partner of this project, wishes to acknowledge the contributions of many experts who have provided valuable inputs, advice and comments into the production of this Handbook.

The preparation of this publication was done by Kaltech Solutions, under the oversight of Mr. Sridhar Samudrala, WADE Director for Asia. Inputs and guidance have been provided by the following members of the Smart Thai team:

- Mr. Vazzan Tirangkura - Programme Coordinator
- Mr. Alan Dale Gonzales - Public-Private Partnership Specialist
- Mr. Supasit Amaralikit - Techno-Economic Specialist
- Dr. Ludovic Lacrosse - CDM Specialist
- Mr. David M. Sweet - Regulatory/Legal Specialist
- Ms. Ornthipa Mongkolsawat - Project Manager
- Mr. Bienvenido Anatan - WADE THAI
- Mr. Juergen Bender - External Resource Expert (Orga Systems)
- Mr. Ayush Jain - Intern
- Mr. Ankit Gupta - Intern

WADE THAI greatly appreciates the strong support, essential collaboration and very useful contributions provided by the following Government agencies through their participation and interaction during the dialogues, corporate exchanges, workshops and seminars in Thailand and Europe, which have been the basis for the preparation of some sections in this Handbook:

- Energy Policy and Planning Office (EPPO)
- Department of Alternative Energy Development and Efficiency (DEDE)
- Energy Regulatory Commission of Thailand (ERC)
- Electricity Generating Authority of Thailand (EGAT)
- Provincial Electricity Authority (PEA)
- Metropolitan Electricity Authority (MEA)

Finally and most importantly, sincere gratitude is due to the European Union whose grant funding made possible the preparation of this Handbook.
It is generally acknowledged that well designed Smart/Intelligent Grids will help reduce transmission and distribution losses while optimising the use of existing infrastructure. This is achieved by automatically controlling the power flows while meeting, and in some cases reducing, peak demand. Moreover, a properly engineered system can allow the addition of distributed/renewable energy into the grid at economical rates. This integration into the grid will improve efficiency of the electrical power system by managing the consumption patterns of new and existing users who are connected to the grid.

The major benefits of Smart Grid systems include reduction of carbon emissions and improvement of energy efficiency, leading to environmental sustainability and lower electricity prices to consumers. By implementing Smart Grid systems, utilities could generate and distribute more affordable electricity, which in turn could stimulate greater economic activities in communities and activities that could lead to more productivity of, and benefits to, women and children.

In Thailand, it is estimated that introduction of Smart Grid systems would result in an overall reduction of energy consumption by as much as 9% and a total reduction in carbon dioxide emissions of 12%. Smart Grids are designed to benefit the consumers, energy producers and not least importantly, the environment.

By preparing this “Handbook on Smart/Intelligent Grid Systems Development and Deployment”, we aim to produce a reference and resource that stakeholders could use in studying and understanding the concepts, issues and best practices related to Smart Grid systems that could be applicable to the Thai context. This is the first for a Handbook in this subject to be produced for Thailand and I hope that Thai executives, senior managers, policymakers and regulators would find this document informative and useful.

We are especially thankful to the European Union for providing funding for the production of this Handbook; to the experts and contributors, whose joint efforts have made the completion of this Handbook a reality; and to the relevant Government agencies (EPPO, DEDE, ERC, EGAT, PEA, MEA,) for their partnership and valuable inputs.

ALAN DALE C. GONZALES
Chairman
World Alliance for Thai Decentralised Energy Association (WADE THAI)
The world is changing and has to utilise its resources in a more efficient and environment-friendly manner while providing the economy with quality power. This transition towards a more efficient low-carbon economy necessitates a change in the way power is produced, transmitted, distributed and consumed. Smart Grids are now being developed to meet this growing demand and fulfil the stringent regulatory mechanisms for utilising new smart technologies.

Most of the world’s electrical delivery system or “grid” was built when energy was relatively inexpensive. There have been some upgrades to meet the growing demand; however, the grid still operates like it did over a century ago – energy flows over the grid from central power stations to customers and reliability is ensured by maintaining excess capacity. This old grid is inefficient and environmentally wasteful, emitting greenhouse and other pollutive gases, consuming large quantities of fossil fuels, and certainly not well suited to take advantage of the new technologies developed in communication, distributed/renewable energy (i.e. wind, solar or hydro) and smart appliances.

The recent surge in energy prices and increased demand in the international market has renewed the continuing concerns of both governments and individuals regarding our rapidly depleting fossil fuel resources.

Smart Grid may be an essential element to facilitate the transformation of the electric industry into a smart world.

This Handbook on Smart/Intelligent Grid Systems Development and Deployment is designed to provide executives, senior managers, policymakers, regulators, industrialists and other stakeholders in Thailand with relevant information in understanding, assessing and quantifying opportunities and potential benefits that a Smart Grid may provide. The handbook specifically reviews and delineates:

- the benefits of a Smart Grid system, along with a summary of its technologies;
- the barriers and challenges that need to be overcome to enhance the grid;
- opportunities and recommendations for Smart Grid development in Thailand; and
- case studies for Smart Grid system deployment, particularly in Europe.

**Introduction to Smart Grid**

Smart Grid is a digital, self-healing energy system that delivers electricity or gas from generation sources, including distributed renewable, to points of consumption. It is capable of optimising power delivery and facilitating two-way communication across the grid, enabling end-user energy management, minimising power disruptions and transporting only the required amount of power. The result is lower cost to the utility and the customer, more reliable power and reduced carbon emissions.¹

The electricity systems in the world are changing to accommodate the growing demand of electricity while providing economically and environmentally safe energy. The utilities and energy providers are incorporating newer technologies (e.g. meters, transformers, communication devices) available in the market. This Smart Grid integrates new communication/technologies and allows the electric

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¹ Accelerating Successful Smart Grid Pilots, World Economic Forum 2010
grid to be more energy efficient through Demand Side Management (DSM) and Integrated Resource Planning (IRP). DSM is the use of information and communication on the consumer side to provide for more efficient use of the distribution grid. IRP is the process electric and gas utilities use to estimate short/long term load growth and decide on the most efficient mix of energy sources to meet the growth. DSM/IRP allows customers/utilities the benefits of a more efficient grid that produces electricity in a cost-effective, environmentally-sound manner.

Smart Grid Development in Thailand

In Thailand, the major Smart Grid stakeholders include the following leading agencies: Energy Policy and Planning Office (EPPO), Ministry of Energy; Energy Regulatory Commission (ERC); Electricity Generating Authority of Thailand (EGAT); Provincial Electricity Authority (PEA); Metropolitan Electricity Authority (MEA); and the Department of Alternative Energy Development (DEDE), Ministry of Energy.

The Ministry of Energy appointed a subcommittee to create the National Smart Grid Development Master Plan on December 8, 2011. The master plan for Thailand’s Smart Grid Development for the next 20 years (until 2030) is being prepared by the EPPO. Likewise, EGAT, PEA, and MEA as part of the Smart Grid subcommittee are also developing their own Smart Grid Roadmaps in accordance with the national master plan.

The stakeholders have identified the key drivers to Smart Grid development in Thailand as:

- transition to low carbon economy
- promotion of renewable energy and energy conservation
- need of energy efficiency development to reduce operating cost in manufacturing sector
- development of a power system and power trade in the ASEAN Power Grid for power system security and increasing electricity demand
- transition to electric vehicles
- potential on Smart Grid technology development for economic value added

Smart Grid Technologies

Smart Grid Technologies have been reviewed and categorised into its main components as follows:

1) Smart Power Generation. This includes power generated from renewable sources such as hydropower, wind energy, biomass, and geothermal energy. Grid energy storage technologies also include mechanical technologies such as pumped hydroelectric storage, compressed air energy storage and flywheel storage while electrochemical/battery technologies are lead-acid batteries, lithium-ion batteries, sodium-based batteries, vanadium redox batteries, and liquid metal batteries.

2) Smart Transmission Grid Application. The technologies for smart transmission include wide-area control; frequency control; regional voltage control, small signal stability control; voltage stability control; transient stability control; ‘soft-wired’ special protection schemes; online setting of special protection schemes; real-time control of transient stability; and real-time modeling (state estimation).

3) Distribution Automation. The applications discussed were substation automation and IEC 61850, and distribution feeder automation (feeder remote terminal unit).
4) Customer Home Automation and Demand Response. The technologies covered include advanced metering infrastructure (Smart Meters); electric vehicles and its supporting infrastructures; and customer power management.

Other important Smart Grid components were considered such as integration-interconnection standards with renewable sources of energy; distribution network topology; information communication and wireless technology.

Barriers to Smart Grid Deployment

The electrical systems in the world are changing and the developed world is integrating some new technologies to improve the energy efficiency of the electrical system. Smart Grid is a concept that will save the government, energy companies, utilities, and customer money and resources in the long term. In order to implement the Smart Grid system, there are many obstacles that must be overcome. Some of the major barriers to Smart Grid development and deployment involve the development of standards and protocols, customer education and engagement, large funding and investment costs, security concerns, and regulatory barriers.

Smart Grid Challenges

The new Smart Grid will integrate digital technology to improve reliability, efficiency, flexibility, and decrease electricity costs to the utility and end users. The will and mechanism to achieve this vision hinges upon activities that directly address the technical, business, and institutional challenges to realising a smarter grid. These key activities strategic in the shift towards a Smart Grid system are:

Interoperability and Standards - Activities must ensure that new devices will interoperate in a secure environment as innovative digital technologies are implemented throughout the electricity delivery system. The ongoing Smart Grid interoperability process promises to lead to flexible, uniform, and technology-neutral standards that enable innovation, improve consumer choice and yield economies of scale. Activities in the domain of interoperability and standards are not limited to technical information standards; they must be advanced in conjunction with business processes, markets and the regulatory environment.

Interconnection Planning and Analysis - Activities must create greater certainty with respect to future generation, including identifying transmission requirements under a broad range of alternative electricity futures (e.g. intensive application of demand-side technologies) and developing long-term interconnection-wide transmission expansion plans.

Workforce Development - Workforce development intends to address the impending workforce shortage by developing a greater number of well-trained, highly skilled electric power sector personnel knowledgeable in Smart Grid operations.

Stakeholder Engagement and Outreach - Stakeholder engagement and outreach activities will identify R&D needs for planning, sharing of lessons learned for continuous improvement, and exchanging technical and cost performance data. This should help inform decision makers about Smart Grid technology options and facilitate adoption of applicable systems, regulations and technologies.

Monitoring National Progress - Monitoring national progress activities will establish metrics to show progress with respect to overcoming challenges and achieving Smart Grid characteristics.
Key Strategies to Overcome Barriers in Thailand

Smart Grids have multiple operational mechanisms and have no single shape. Thailand has many opportunities to enhance the grid and provide energy in an efficient and environmentally sound manner. The following are some recommendations to hurdle the existing barriers surrounding the development and implementation of a Smart Grid system in Thailand:

1. Standardise the Smart Grid definitions and interfaces with the government, regulators, and utilities while setting product requirements and applications. The government, regulators, and utilities should create a strategy and develop standards in participation with industry and stakeholders on an international level to ensure interoperability of system components and reduce risk of technology obsolescence.

2. The government and regulators should collaborate with public/private sector stakeholders to determine regulatory and market solutions that can mobilise private sector investment in the energy sector.

3. Regulators should create, promote, and adopt a real-time energy usage tariff – Generators, transmission system operators, and distribution companies should plan and operate the systems in a coordinated manner.

4. Transmission and distribution system operators should work in coordination to develop operational business models with government and regulators, which ensure that all stakeholders share risks, and are shown the benefits of system reliability, cost, environmental sustainability and security.

5. Generators should be flexible on the methods used by the Smart Grid to meet demand growth and decrease emissions.

6. Create a mechanism for the utilities to invest in research, development and demonstration. The government should actively engage in developing system demonstrations and deployments in order to ensure consumer contribution to and benefit from future electricity systems and markets, while ensuring consumer protection.

7. Reform the power planning process so that it becomes an integrated resource planning (IRP) process, overseen by the energy regulator, in which all alternatives are considered (including energy conservation and renewables) and through which utilities are required to choose the option with the lowest overall economic cost to society, as opposed to the lowest commercial cost to the state generator EGAT. Integral to the achievement of this recommendation is the completion of comprehensive assessment of the externality costs of different fuels and generating technologies in the Thai context.

8. Introduce feed-in tariffs for specific renewable technologies to encourage deployment.

9. Change policy to put energy saving at the forefront of the energy agenda and remove the barriers that limit Distributed Energy (DE).
Additionally, in order for Smart Grid to be incorporated in the policies of the government, there are several regulatory challenges that need to be addressed. Smart Grid deployment should be first and foremost market-driven. Investors want the regulatory framework changed to allow greater competition in the distribution sector and the recovery of investments. Possible improvements in this regard include:

- The Regulatory Commission should develop regulatory incentives for the deployment of Smart Grids; for example, revising the tariff mechanism to accommodate and encourage implementation of Smart Grid systems;
- Guidelines to define a methodology for the smart meter implementation and cost-benefit analyses;
- Guidelines for increased renewable energy sources to be incorporated by the utilities;
- Requirements for the format and content of information provision for customers, and for access to information services and demand management (e.g. in-house control of consumption);
- Creation of a transparent and competitive retail market for the development of services (e.g. time-of-use pricing and demand response) based on Smart Grids and metering.

**Recommendations for Smart Grid Implementation in Thailand**

In summary, these are the suggestions and recommendations for Thailand as it progresses its way to implementing a Smart Grid system in the country.

**Smart Grid Certification** - In order to promote and enhance the Smart Grid schemes, there is a strong case for standardised certification and permitting rules for new schemes with pre-defined technical requirements and that the certification process should be made legally binding, administered fairly by approved agencies. Alternatively, compliance with some of the technical performance requirements of the system specification could be verified through manufacturer “self-certification”, reducing the financial burden associated with employing a third party assessor. For this matter, it is recommended that:

- standardised Smart Grid devices/systems integration certification and authorisation protocols be developed and implemented; and
- system manufacturers should be permitted to “self-certify” certain aspects of the performance of their systems in order to minimise the financial burden associated with the certification process.

**Smart Grid Incentives and Financing** - The installed costs of newer technologies (e.g. Smart meters, automation, Distributed Generation (DG), fuel cells, micro turbines, etc.) are currently too high. The higher cost factor is disabling them to achieve a significant market penetration breakthrough without some degree of cost reduction. Thailand may offer sufficient incentives to enable developments to take place, whilst ensuring that manufacturers are encouraged to develop genuinely “commercial” systems. It is recommended that a:

- full assessment be performed to determine appropriate, fair and consistent incentive regimes. These incentives must both encourage the uptake of new technologies and lead to the commercial development of these technologies while enabling them to compete and maintain market share in the long term; and
- detailed financial model of the entire power market for Thailand be developed, with the purpose of enabling the impacts of different incentive schemes on the penetration of different technologies. Such a model will also enable a pro-active response to changes in market structure and technology developments by policy makers through changes in incentives and other mechanisms.
**Coordination of Smart Grid Activities** - At the current time there are limited activities, both at the long-term fundamental research stage and at the nearer-term commercialisation stage. There is a general lack of cohesion and strategic focus pulling all the research and development activities together in the same direction for the good of Thailand. Therefore, it is recommended that:

- Thailand should give consideration to increasing research and development support for Smart Grid technology developments, and to increasing developmental funding;
- Given the high strategic importance of developing a successful Smart Grid, an industry research and development coordinating group be convened to promote its benefits. It is considered that the best way to achieve this is by setting up such a group in a dedicated “Smart Grid Office” located in Bangkok; and
- This group be a centre of competence and information on Smart Grid issues for stakeholders; providing a focal point for Smart Grid technology and institutional barrier removal; providing guidance for the coordinated and directed support of Smart Grid technology development support; and continuously maintained database of the power sector and Smart Grid statistics which could be systematically and protectively assessed.

**On Feed-In Tariffs** - As a development mechanism to accelerate the Smart Grid implementation and encouraging decentralised/renewable energy, it is recommended to establish feed-in tariffs so that the benefits have time to accumulate. It is also necessary to put in place mechanisms to strengthen the programme in the long term through review/adjustment of tariff levels every two years, and putting in place a stable legal basis on parliamentary law. The following actions are highly recommended:

- Arrive at mutually agreed-up principles for determining feed-in tariff levels;
- Arrive at mutually agreeable initial feed-in tariff levels for different technologies. The levels proposed by various Thai actors for biomass, biogas, wind power and micro-hydropower are all broadly reasonable while the levels for MSW and solar power should be trimmed;
- Establish a legal basis for feed-in tariffs. In the short term, this could take the form of a Cabinet Resolution. However, work should also be initiated to develop a full renewable energy law to be passed by Parliament in order to provide sufficient long-term assurances to investors that the feed-in programme will be in existence long enough to justify investment;
- Generators to have guaranteed access to the grid (already partially in place);
- Capacity and the authority to levy fines; and
- Conduct externality study.

**Improve the Regulatory and Policy Framework** - Thai authorities should take the lead and develop specific policy documents and regulations on cyber security and privacy of the Smart Grid in order to improve the regulatory and policy framework. Thailand may want to review the European security protocols for Smart Grid development and take into account existing regulations and policies on smart grid, challenges, goals and needs of cyber security for the grid. It is recommended to:

- Define security measures to be considered in current Smart Grid deployments (e.g. smart meter roll-outs);
- Demand grid operators for security risk assessments;
- Establish regulatory pressures (e.g. fines) for not complying with the rules and regulations;
- Demand manufacturers, integrators, services providers and grid operators to comply with specific security certifications; and
- Demand operators to report on cyber security related incidents.
Customer/Manufacturer and Utility Awareness - Before implementing Smart Grid concepts, Thailand must consider educating the public about the Smart Grid, its benefits and contribution to the economy. Utilities, grid operators, electricity services providers, and manufacturers should be made aware of their responsibilities, and training initiatives be conducted on how to build secure devices and applications. It is recommended that Thailand’s stakeholder agencies intentionally:

- Enhance communication among Customers and the Utility;
- Organise technical events for raising awareness and training;
- Prepare appropriate media for raising awareness on Smart Grid security aspects;
- Define a clear and unified strategy for ongoing and new initiatives;
- Identify Smart Grid initiatives;
- Set up a centre of excellence for Smart Grid; and
- Define system-wide technical terms.

Coordinate Large/Small Scale Energy Integration into the Smart Grid - Thailand authorities should consider a study/strategy to coordinate the integration of renewable/decentralised energy into the grid. This integration will affect the grid stability and security. They should study the convenience of a central coordinating entity for the grid and also the small mini/micro grids that may develop as a result of the new renewable and decentralised energy policy. The concerned agencies such as PEA, MEA, EGAT, EPPO, DEDE and ERC need to focus on these technical capabilities of Smart Grids:

- Security monitoring sensors should be distributed across the grid gathering data that could be processed in a decentralised or centralised manner;
- A central monitoring centre for data collection and analysis may be created/adopted;
- Signature-based software will be needed in sensors;
- Monitoring centres could also perform research activities (e.g. write new signatures, study new grid operating methods)

Case Studies from Denmark, Germany and France

The landmark Smart Grid projects that have been successfully implemented in Europe offer many learning opportunities for other countries that are seeking to benefit from the advancements in the power industry. The case studies on the EcoGrid project in Denmark, E-Energy Project - MeRegio in Germany, and the Linky Project in France showcase the various initiatives, policies and best practices in Smart Grid systems implementation. As the subject matter of Smart Grid is relatively new, there are many issues and concepts that are considered complex and unclear to many. However, with the achievements demonstrated by these particular projects, valuable information from proven models were made available, particularly in addressing common Smart Grid issues such as how to: increase renewable energy mix, create market and regulatory framework; conduct effective consumer information drives; approach implementation timelines; form linkages and network partnerships; and run pilot projects on the use of smart meters.

In conclusion, Thailand’s power industry is changing and calls for a switch into the next generation Smart Grid system through automation. The country can begin with basic automation systems eventually upgrading to the advanced systems by 2025. By analysing the growing power demand and market competence, this is one of the ways-forward for the power industry to decrease its future costs and reduce its carbon footprint. The development and deployment of a Smart Grid system is not going to be an easy task as the power sector poses a number of issues such as minimising transmission and distribution losses, inadequate grid infrastructure, low metering efficiency and lack of awareness.
PART I
INTRODUCTION TO SMART GRID
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The world is interconnected in many ways and industry is primarily driven by communication, transportation and energy. As communication and transportation developed, the industry requirement for energy grew exponentially. However, the electricity sector has not advanced at the same pace. Over the past century, the electricity grid grew from local grids to interconnected grids for reliability reasons. The electricity grid is still focused on central power generation stations where the generator is located close to the fuel source and lengthy high voltage transmission lines are used to connect to the distribution network serving the public. The large power stations could not be located near the population/load centres for practical reasons. The rural areas were connected only when economical and in most cases used renewable or decentralised energy.

As the energy sector grew and demand increased for energy, the regulators/governments introduced various metering and tariff mechanisms to control the use of electricity. As industry expanded, demand increased, new power stations were built. However, the electricity grid did not keep pace which led to power cuts, brownouts and eventually blackouts.

In the 20th century with high speed computer and instant communication, energy and electricity patterns were established and the daily peaks were met by small-scale gas-powered generators at load centres. As a result of the new load growth and since the electric utility was unable to meet the demand but was responsible for the quality/quantity/reliability of electricity, they had to procure the energy/electricity from the new generators (often this was expensive and the price was passed on to the customers).

As the grid grew with limited fossil resources, the energy/electric utilities developed new mechanisms to further utilise the existing resources in an environmentally-sound manner. The many advances in the communications are being implemented by the utilities in the grid today to level the variable peaks in the grid.

With concerns regarding the environment, renewable energy (solar, wind and hydro) is playing a vital role in the grid. The decrease in price for renewable energy, coupled with new technologies such as bidirectional meters and net metering, are allowing the use of these renewable sources to be integrated into the grid at the distribution level. This new scenario whereby energy produced is utilised at the point of need changes the grid topography and makes the public less dependent on centralised power stations.

This section aims to present the common understanding of a Smart Grid system. It will also describe the existing electrical power system and how it can possibly evolve into a Smart Grid to keep pace with the changing times. The benefits and issues of Smart Grid systems will be presented, including some details on the current situation of Smart Grid development in Thailand.

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1.1. SMART GRID DEFINITIONS

The most common definition for a Smart Grid is the utilisation of the latest technology in communications to monitor and control the flow of electricity in the most efficient manner. The collection of data acquired from the various points such as the generators, renewable energy providers, homes, industry, is vital in the management of the power grid making it a smart grid.

1.1.1. European Technology Platform for Smart Grids

The concept of Smart Grids was developed in 2006 by the European Technology Platform for Smart Grids. A Smart Grid concerns an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies. This platform is supported by the European Commission with a vision about a bold programme of research, development and demonstration that charts a course towards an electricity supply network that meets the needs of Europe’s future.

A Smart Grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies in order to:

- Better facilitate the connection and operation of generators of all sizes and technologies;
- Allow consumers to play a part in optimising the operation of the system;
- Provide consumers with more information and options for choosing an energy supply;
- Significantly reduce the environmental impact of the whole electricity supply system;
- Maintain/improve the existing high levels of system reliability, quality and security of supply;
- Maintain or improve the efficiency of existing services; and
- Foster the development of an integrated European market.

The Smart Grid European Technology Platform envisions that Europe’s electricity networks in 2020 and beyond will be:

- Flexible – fulfilling customers’ needs whilst responding to the changes and challenges ahead;
- Accessible – granting connection access to all network users, particularly for renewable energy sources and high efficiency local generation with zero or low carbon emissions;
- Reliable – assuring and improving security and quality of supply, consistent with the demands of the digital age; and
- Economic – providing best value through innovation, efficient energy management and ‘level playing field’ competition and regulation.

3 Smart Grids European Technology Platform for Electricity Networks of the Future
1.1.2. World Economic Forum

According to the World Economic Forum (WEF), a Smart Grid is defined as a digital, self-healing energy system that delivers electricity or gas from generation sources, including distributed renewable, to points of consumption. It is capable of optimising power delivery and facilitating two-way communication across the grid, enabling end-user energy management, minimising power disruptions and transporting only the required amount of power (see Figure 1). The result is lower cost to the utility and the customer, more reliable power and reduced carbon emissions.6

Key transitions to progress from the current state of electricity networks to modern utility or a Smart Grid is summarised in Figure 2.

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4 World Economic Forum
5 Accelerating Successful Smart Grid Pilots, World Economic Forum 2010
1.1.3. Thailand Smart Grid Development

Thailand is developing its own National Smart Grid Development Master Plan for the country under the Energy Policy and Planning Office (EPPO) of the Ministry of Energy. The working group under the Thailand Smart Grid Subcommittee includes the Electricity Generating Authority of Thailand (EGAT), Provincial Electricity Authority (PEA), and the Metropolitan Electricity Authority (MEA). Each of these stakeholders is also developing their own Smart Grid roadmaps.

The Smart Grid subcommittee defines the Smart Grid system as an electricity network with the application of Information and Communication Technology (ICT) in the management, control of power generation, transmission and distribution. The Smart Grid system can support the interconnection of Renewable Energy (RE) generation or Distributed Generation (DG) and optimisation asset management as well as more reliable, efficient and quality service provision to customer with smart meters installation.

The Thailand Smart Grid development aims to address two major issues:

(1) Energy and environment situations, e.g. fossil fuel use reduction, promotion of renewable energy generation, environmental impact mitigation; and

(2) Energy infrastructure, e.g. increasing power security, increasing quality of service, support technology development in the future.

The key drivers for the Thailand Smart Grid Development include the following:

- Transition to Low Carbon Economy;
- Promotion of Renewable Energy and Energy Conservation;
- Need of Energy Efficiency development to reduce operating cost in manufacturing sector;
- Development of power system and Power Trade in ASEAN Power Grid for power system security and increasing electricity demand;

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6 Thailand Smart Grid Development, EPPO
• Transition to Electric Vehicles; and
• Potential on Smart Grid Technology Development for Economic Value Added.

Figure 3 illustrates the Thailand Smart Grid Master Plan that aims to cover Smart Grid strategies and objectives in the following areas:

• Security: Power Reliability and Quality
• Sufficiency: Energy Sustainability and Efficiency
• Efficiency: Utility Operation and Service
• Competitiveness: Economic and Industrial Stimulus
• Awareness: Integration and Interoperability

**Figure 3. Thailand Smart Grid Master Plan: Strategies & Objectives**
(Source: Thailand Smart Grid Policy Plan and Roadmap)

1.2. ELECTRICAL POWER SYSTEMS TODAY AND ITS FUTURE

The electrical power system is simple and divided into three zones - generation, transmission and distribution. Power is generated from various energy sources such as gas, coal, nuclear or renewable sources. The transmission lines carry the power from the generator to the distribution system. The distribution process then sends the low voltage electricity to all commercial, industrial and residential customers. This entire system is called the electrical power grid.
1.2.1. Today’s Electrical System

The existing power system is a network of electrical components used to supply, transmit and distribute electricity to the customers. This electricity is sent through the grid. This electricity is mostly upon three-phase Alternating Current (AC).

There are also smaller mini and micro grids that operate when not connected to the main grid. Additionally, there is the Direct Current (DC) where the voltage and current are kept constant. Most equipment in today’s systems uses AC (i.e. commercial and industrial pumps, compressors, refrigerators, air conditioners). Computers and constant power equipment use DC. AC power has the advantage of being easy to transform between voltages while DC power is the main choice in digital systems and can be more economical to transmit over long distances at very high voltages.

The generators are normally very close to the source of fuel (i.e. coal, gas, hydro or nuclear) and very far from the load centres. This power must then be sent to the load centres via high voltage transmission over long distances. In order to keep the losses over the transmission lines low, the voltage is stepped up at the generation station sent thru the transmission lines and then stepped down near the load centres. This method minimises the power losses. An illustration of today’s electrical system is shown in Figure 4. The major components of today’s electrical system are discussed in the succeeding paragraphs.

![Figure 4. Today’s Electrical System](http://elecinfo4all.blogspot.com/2011/01/electrical-power-systems-introduction.html)

A. Generators

The majority of the world’s power still comes from coal-fired power stations. There have been a wide range of technologies used to generate power – heat generated by fossil fuel (coal, gas and oil), nuclear, hydro, wind, solar, and other renewable sources.
Today’s power grid connects these generators in various locations to the load centres via transmission lines. In order to bring all this power to the grid, there are many considerations based on the loads such as source and availability of generation (fossil or renewable), cost of generation or transmission congestion on lines. The market/system operator will play a very important role in deciding these factors.7

B. Load Centres

The power sent to the grid must be monitored and controlled and the system operator does this. They must ensure that the grid voltage, frequency and amount of power supplied to the loads are within the operating limits. This is one of the great challenges of power system engineering. In addition to the real power used by the load centres to do work, many alternating current devices also use an additional amount of reactive power because they cause the alternating voltage and alternating current to become slightly out-of-sync. Reactive power must be balanced and can be supplied from the other generators.8

The power systems deliver energy from load centres to commercial, industrial and residential customers. Most items found in the homes operate on a single-phase at 50 or 60 Hz between 110 and 260 volts. All electrical devices will also have a wattage that specifies the amount of power the device consumes. At any one time, the net amount of power consumed by the loads on a power system must equal the net amount of power produced by the supplies less the power lost in distribution/transmission.9 10

Power quality is also very important and is maintained by the system operator. Changes in voltage, frequency, phase imbalances and power factor are variables that will affect the overall efficiency of the power grid.11 For an AC supply, the ideal is the current and voltage in-sync fluctuating as a perfect sine wave at a prescribed frequency with the voltage at a prescribed amplitude. For DC supply, the ideal is the voltage not varying from a prescribed level. Power quality is especially critical for industrial or hospital equipment.

C. Transmissions and Distribution Systems/Conductors

Electricity is carried from the generator by conductors or the transmission system (voltages greater than 50 kV) or distribution system (voltages less than 50kV).12 Most of the transmission/distribution lines are overhead lines made of reinforced steel or aluminum alloys.13 Overhead conductors are air insulated and supported on porcelain, glass or polymer insulators. Conductors used for underground transmission or building wiring are insulated with cross-linked polyethylene or other

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9 Electricity around the world, Conrad H. McGregor, April 2010.
11 Brief power quality tutorials for engineers, PSL, accessed on 21st, August, 2010.
13 Practical Applications of Electrical Conductors, Stefan Fassbinder, Deutsches Kupferinstitut, January 2010.
flexible insulation. Conductors are typically rated for the maximum current that they can carry.

D. Capacitors and Reactors

The majority of the load in a typical AC power system is inductive – that is, the current lags behind the voltage. Since the voltage and current are out-of-sync, this leads to the emergence of a “useless power” known as reactive power. Reactive power does no measurable work but is transmitted back and forth between the reactive power source and load every cycle. This reactive power can be provided by the generators themselves, but it is often cheaper to provide it through capacitors. Hence, capacitors are often placed near inductive loads to reduce current demand on the power system. Power factor correction may be applied at a central substation or adjacent to large loads.

Reactors consume reactive power and are used to regulate voltage on long transmission lines. In light load conditions, where the loading on transmission lines is well below the surge impedance loading, the efficiency of the power system may actually be improved by switching on reactors. Reactors installed in series in a power system also limit rushes of current flow. Small reactors are therefore almost always installed in series with capacitors to limit the current rush associated with switching in a capacitor. Series reactors can also be used to limit fault currents.

Capacitors and reactors are switched by circuit breakers, which results in moderately large steps in reactive power. A solution comes in the form of static volt-ampere reactive (VAR) compensators and static synchronous compensators. Briefly, static VAR compensators work by switching in capacitors using thyristors as opposed to circuit breakers allowing capacitors to be switched-in and switched-out within a single cycle. This provides a far more refined response than circuit breaker switched capacitors. Static synchronous compensators take it a step further by achieving reactive power adjustments using only power electronics.

E. Power Electronics

Power electronics are semi-conductor based devices that are able to switch quantities of power ranging from a few hundred watts to several hundred megawatts. Despite their relatively simple function, their speed of operation (typically in the order of nanoseconds) means they are capable of a wide range of tasks that would be difficult or impossible with conventional technology. The classic function of power electronics is rectification, or the conversion of AC-to-DC power. Power electronics are therefore found in almost every digital device that is supplied from an AC source.

High-voltage direct current (HVDC) is used because it proves to be more economical than similar high voltage AC systems for very long distances (hundreds to thousands of kilometers). HVDC is also desirable for interconnects because it allows frequency independence thus improving system stability. Power electronics are also essential for any power source that is required to produce an AC output but that by its nature produces a DC output such as photovoltaic installations.

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14 Naval Engineering Training Series (Figure 1.6), U.S. Navy (republished by tpub.com), 2007.
15 Switching Characteristics of Thyristors During Turn-On, [electricalandelectronics.org], April 9, 2009.
Power electronics are also at the heart of the variable-speed wind turbine. Put simply, conventional wind turbines require significant engineering to ensure they operate at some ratio of the system frequency (the ratio being accounted for using gears), however by using power electronics this requirement can be eliminated as can the gears leading to quieter, more flexible and (at the moment) more costly wind turbines.

F. Protective Devices

The electrical power system is complicated and has many components and requires protection for the equipment. The most common protective devices include the fuse, circuit breakers and protective relays that detect a fault and initiate a trip. Different relays will initiate trips depending upon the kind of electrical system designs.\(^\text{17}\)

G. Supervisory Control and Data Acquisition (SCADA)

In large electric power systems, Supervisory Control and Data Acquisition (SCADA) is used for tasks such as switching on generators, controlling generator output and switching in or out system elements for maintenance. Today, SCADA systems are much more sophisticated and, due to advances in communication systems, the consoles controlling the plant no longer need to be near the plant itself.

1.2.2. Future Electrical System

Figure 5 illustrates a transition from today’s traditional electrical grid to the electrical system of the future, the Smart Grid. This future grid is only possible if today’s technology and intelligence is integrated into the existing grid.

\(^\text{17}\) How does an RCD work?, PowerBreaker, accessed on 14-Mar-10.
In the telecommunication industry for instance, smart phones have evolved because it has incorporated telephones with computers. Today’s grid will need to incorporate computing into the grid, which could be done by using computer-based remote control and automation systems. These systems are made possible by two-way communication technology and high speed computer processing. In the past, utility sent workers out to get the data required to provide electricity. The workers read meters, looked for broken equipment and measured voltage.

The future will have sensors and include two-way digital communication technology to various devices located in the grid. Devices such as meters, voltage sensors or fault detectors would be able to gather information, analyse it and make the necessary corrections to the grid accordingly. The primary function of the future grid will be to increase efficiency and minimise losses thru grid automation technology. The automation will allow the utility to adjust and control millions of devices from a central location. Figure 6 shows further how a Smart Grid is envisioned for the future.
The number of applications that can be used on the Smart Grid once the data communications technology is deployed is growing as fast as inventive companies can create and produce them. Benefits include enhanced cyber-security, handling sources of electricity like wind and solar power and even integrating electric vehicles onto the grid. The companies making smart grid technology or offering such services include technology giants, established communication firms and even brand new technology firms.

1.3. SMART GRID BENEFITS AND ISSUES

The electricity systems in the world are changing to accommodate the growing demand of electricity while providing economically and environment-friendly energy. The utilities and energy providers are incorporating newer technologies available in the market. This Smart Grid integrates new communication technologies and allows the electric grid to be more energy efficient thru Demand Side Management (DSM) and Integrated Resource Planning (IRP). DSM is the use of information and communication on the consumer side to provide for more efficient use of the distribution grid. IRP is the process that electric and gas utilities use to estimate short/long term load growth and decide on the most efficient mix of energy sources to meet the growth. DSM/IRP allows customers/ utilities the benefits of more efficient grid in a cost-effective, environmentally sound manner.
1.3.1. Why Implement a Smart Grid: The Benefits

The Smart Grid is a valuable asset as it can provide a number of benefits to the customer, utility and environment. Recent estimates from United States show the annual cost of power interruptions are approximately US$80 billion.\textsuperscript{18} Other reports show the estimated cost of electric outages is well over US$100 billion annually. With total annual electric industry revenues at roughly US$326 billion, these costs represent a significant burden on the consumers.\textsuperscript{19}

The use of Smart Grid technologies are designed to help mitigate or reduce the price of electricity through the interaction of the demand side management of the market (consumers) with the Integrated Resource Planning - supply side (suppliers). Reports have also shown that Smart Grid will enable other organisations like the Electric Service Company (ESCO) to provide mechanisms, new products and services which can give consumers greater choice and flexibility in energy consumption.

Grid operations, utilities, and most importantly consumers, will benefit from improved operational efficiency. Smart Grid optimises the use of the grid assets. Smart grid policies will also be required to improve security and safety by reducing the vulnerability of the grid to unexpected hazards and promoting a safer system for both workers and the general public. The Smart Grid will promote environmental quality by allowing customers to purchase cleaner, lower-carbon-emitting generation, promote a more even deployment of renewable energy sources, and allow access to more environment-friendly central station generation.

Furthermore, the Smart Grid will allow for more efficient consumer response to prices, which will reduce the need for additional fossil fuel-fired generation capacity, thereby reducing the emission of carbon dioxide and other pollutants.

There are multiple benefits from increasing the reliability of the power system and switching to a Smart Grid is a critical step towards this. The benefits to the multiple stakeholders in a Smart Grid system are described as follows:

A. Residential and Small-scale Commercial Customers

The Smart Grid will provide for greater system reliability. The increase in reliability will enable customers to control their energy consumption. The Smart Grid provides customers new tools to manage their usage and total energy bill by making information available on a real time basis. This new information can allow the customer to use the electricity at the best prices based on their requirements. Finally, by connecting prices and quantity of usage, customers will be transformed from passive “ratepayers” to active, engaged participants in electricity markets.

B. Low-income Customers

A more reliable grid will limit the risk of outages and reduce the need for new generation, transmission, and distribution facilities. The Smart Grid is designed to lower the overall price of electricity and therefore benefit low income customers.


\textsuperscript{19} 2006 data from: http://www.eia.doe.gov/cneaf/electricity/epa/epat7p3.html
C. Large-scale Industrial Customers

The industrial and commercial sectors are the biggest beneficiaries, as they will be able to have access to real-time pricing information. This will enable them to make efficient energy decisions in the wholesale energy market. The Smart Grid will allow large industrial and commercial customers to integrate their production, storage and efficiency investments easily that may result in lower cost of production.

D. Local Governments

Local governments can benefit from higher reliability and lower duration of outages. The more information that is available, the quicker the government can respond to disturbances and emergencies such as fires, police matters and natural disasters.

E. Utility/Grid Operators

Utilities and grid operators can reduce overall costs by increasing reliability and outages. This will result in greater customer satisfaction. The utility direct costs will be reduced by decreasing time for meter reading, decreased labor for down time by field staff, increased efficiency of billing, and many other utility-related items. In developing countries, other benefits include decrease in working capital needs and most importantly reduction in energy loss and theft.

F. Economies

The local economy is bound to benefit as the cost of services and electricity will decrease over time. This will lead to greater investment and use of capital for other expenditures. Modern electricity infrastructure can also protect the environment, which in turn can reduce health-care-related costs.

1.3.2. Why Smart Grid is Not a Common Feature in Today’s Utilities: The Issues

Some key issues that keep the Smart Grid from being widely used in today’s electrical system are identified below:

A. Customer Involvement

In order for the Smart Grid to be incorporated, the customers must be involved in the details. With a wide range of customers and their knowledge of the complicated systems involved, the pace has been slowed for the smart grid deployment. For example, the Pacific Gas and Electric Company in California is facing a class action lawsuit from its customers, because they were not involved in the grid development. This was a major setback after the utility invested millions for grid improvement.

Solution: By involving the customers, utilities can incorporate the plans as required by the community leading to a peaceful and involved Smart Grid that meets the requirements of the people. The main consideration is that all information and data be represented in a meaningful format that is understood by the customer. A good example of this customer involvement is how the National...
Grid worked with the City of Worcester to update their electrical grid systematically. They conducted community summits, programs, and a university demonstration centre. The community created 13 new programs, led by either National Grid or the community itself. National Grid, for example, utilised a digital picture frame type display that provided comprehensive graphs for consumption data, as well as additional functionality for the consumer. In New Orleans, Entergy established relationships with non-profit organisations, allowing them to maximise community involvement and provide consumer education in schools, universities and community centres.

B. Employee Involvement

One other reason why the Smart Grid has been slow to take off is the involvement of the employees who have to deal with the customers. Since customers have limited access to the decision making executives in the utility, it is essential that every interaction with the utility employee be a positive one. This makes communication skills extremely important to both technical and non-technical workers alike.

**Solution:** Employees must be empowered to work with the customer and make the experience positive. Utilities are now restructuring the training for the employees so it focuses on mechanisms to develop employee communication with the customers.

C. Interoperability

The largest planning problem utilities typically face in deployment efforts are interoperability issues. The capacity of equipment to be utilised in multiple locations and communicate with other equipment is one of the biggest problems. For example, utilities found that some equipment was produced by vendors that were no longer in business, and identified several integration issues with devices.

**Solution:** Identify and develop solutions for procurement and identify methods for existing equipment early for ways to communicate with every device, using custom coding and creating a Maintenance Management Information System. Utilities are now testing their deployment by installing multiple brands of smart meters and testing them before full-scale deployment in order to implement any necessary changes before deployment occurs on a large scale. The utility can then record organisational responsibilities and procedures to identify areas of inefficiency and improve interoperability.

D. Cost Planning

Improper cost planning and unforeseen cost increases also cause the delay in Smart Grid development. Utilities are going over budget due to a lack of utility, customer and vendor integration and collaboration. The major challenge for implementing Smart Grid is availability of funds. Huge investments are required in order to setup a link between the customers and the Smart Grid.

The cost of setting up more plants can be deferred drastically. Emphasis will be on overall development of Transmission and Distribution (T&D) efficiency based on demand response, load control and many other Smart Grid technologies. With information availability provided by Smart Grid communications, customers would be able to adopt energy-efficient measures. To tackle the Smart Grid future, there needs to be Smart Grid consumer products, collaborative vendor partnerships and a willing investment community.
Solution: Utilities are encouraged to perform a cost-benefit analysis and obtain a “Certificate of Public Convenience and Necessity, from the regulatory commission which would have created a more accurate budget and allowed the utility to cap costs as they were incurred. If this is done the community may get more involved and not resist additional smart grid deployments.

The policy makers and regulators may implement an incentive model framework that can encourage private investments keeping the rate of return attractive. Policy makers and regulators can mitigate expenses by seeking economies of scale and implementing advanced digital technologies. Smart grid deployments have presented many lessons that can improve system efficiency and reliability, and increase profits for utilities. Customers are a key stakeholder and utilities should cultivate these relationships, as well as educate customers in ways that allow them to manage, control, and curb their energy consumption. Utilities that focus on developing employee communication and customer service skills, implement employee training plans, and create interdepartmental management teams are best poised for successful deployments. Proper planning is necessary to ease the transition to a smarter grid. Planning for interoperability and setting realistic expectations will keep the utility focused on maximising benefits while minimising problems.

1.4. CURRENT SMART GRID SITUATION IN THAILAND

According to the policy statement of the Council of Ministers20, Thailand’s Energy Policy indicates the following:

- Promote and drive the energy sector to generate income for the country. As a strategic industry, investment in energy infrastructure will be increased to make Thailand a regional centre for the energy business, building upon the competitiveness of its strategic location.
- Reinforce energy security through development of the electrical power grid and exploration of new and existing energy sources, both in Thailand and abroad. Energy sources and types will also be diversified so that Thailand will be able to meet its energy needs from a variety of sustainable energy sources.
- Regulate energy prices to ensure fairness as well as reflect the production costs by adjusting the role of the Oil Fund into a fund, which ensures price stability. Subsidies will be available for vulnerable groups. The use of natural gas in the transport sector will also be promoted, while the use of gasohol and biodiesel will be promoted for use in the household sector.
- Support the production, use, research and development of renewable and alternative energy sources, with the objective of replacing 25% of the energy generated by fossil fuels within the next decade. Comprehensive development of the energy industry will also be promoted.
- Promote and drive energy conservation through the reduction of power usage in the production process by 25% within the next two decades. The use of energy efficient equipment and buildings will be promoted, while Clean Development Mechanisms (CDM) will be used to reduce emission of Green House Gases (GHGs) and tackle global climate change. Systematically raise consumer awareness to use energy efficiently in order to conserve power in the production and transport sectors, as well as in the household.

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20 Policy Statement of the Council of Ministers, delivered by Prime Minister Yingluck Shinawatra to the National Assembly on Tuesday 23 August 2011.
1.4.1. Energy Policies Relevant to Smart Grid

Thailand has drawn up three major energy-related national development plans that will pave the way towards the country’s successful development and deployment of a Smart Grid system.

A. Power Development Plan (PDP)

Thailand’s Power Development Plan (PDP)\textsuperscript{21} is a 20-year investment plan that specifies which power plants and transmission lines are to be added at what time. A new official PDP is issued about once every two years. The Electricity Generating Authority of Thailand (EGAT) draws a PDP reviewed by the Ministry of Energy and approved by the National Energy Policy Council, then by the Cabinet. After the approval of its PDP, EGAT then undertakes to develop and expand the power system according to the plan.

A national long-term PDP has been revised regularly to best suit the country’s economic and social situations. Based on the policy framework of the Ministry of Energy, the latest plan or PDP 2010 (2010 – 2030) was designated as the “Green PDP” as there is a lot of priority on clean energy and sustainable environment with highlights on reducing GHG emission and promoting efficient energy. Even though there is little mention of the Smart Grid, there are many implications where Smart Grid systems will have significant impact in the areas of energy efficiency and greenhouse gas emissions.

According to Thailand’s Power Development Plan 2012 – 2030 (PDP2010: Revision 3 – June 2012), by the end of 2030, the grand total power capacity will be about 70,686 MW. This will be comprised of the current total capacity (as of December 2011) of 32,395 MW with additional capacity of 55,130 MW less the projected retired capacity totaling 16,839 MW.

The total added capacity during 2012–2019 includes all projects planned with commitment and agreement. The total added capacity will be about 23,325 MW detailed as the following:

- Power purchases from renewable energy: 8,194 MW (domestic and neighboring countries)
- Cogeneration: 5,107 MW
- Combined cycle power plants: 6,551 MW
- Thermal power plants (coal/lignite): 3,473 MW

The total added capacity during 2020 – 2030 comprises all projects planned for serving future power demand increasing annually and also replacement of the retired power plants. The total added capacity during this period will be about 31,805 MW summarised as the following:

- Power purchases from renewable energy: 6,387 MW (domestic and neighboring countries)
- Cogeneration: 1,368 MW
- Gas turbine power plant: (3 x 250 MW) 750 MW
- Combined cycle power plants: (21 x 900 MW) 18,900 MW
- Thermal power plants (coal): (3 x 800 MW) 2,400 MW
- Thermal power plants (nuclear): (2 x 1,000 MW) 2,000 MW

Overall, the PDP envisions the additional capacity during 2012 – 2030 of 55,130 MW to be generated from various power plant types as listed in Table 1.

Table 1: Thailand’s PDP 2012–2030 Projected Additional Power Capacity Sources

<table>
<thead>
<tr>
<th>Power Plant Type</th>
<th>Power Source</th>
<th>Projected Power (MW)</th>
<th>Total Projected Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renewable</td>
<td>Power purchase from domestic</td>
<td>9,481</td>
<td>14,580</td>
</tr>
<tr>
<td></td>
<td>Power purchase from neighboring countries</td>
<td>5,099</td>
<td></td>
</tr>
<tr>
<td>Cogeneration</td>
<td></td>
<td></td>
<td>6,476</td>
</tr>
<tr>
<td>Combined cycle</td>
<td></td>
<td></td>
<td>25,451</td>
</tr>
<tr>
<td>Thermal</td>
<td>Coal-fired power plants</td>
<td>4,400</td>
<td>8,623</td>
</tr>
<tr>
<td></td>
<td>Nuclear power plants</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gas turbine power plants</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Power purchase from neighboring countries</td>
<td>1,473</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Grand Total: 55,130</td>
</tr>
</tbody>
</table>

B. Renewable and Alternative Energy Development Plan for 25% in 10 Years (AEDP 2012-2021)

With the objective to capably develop renewable energy as one of the country’s major energy sources, the Ministry of Energy established the Renewable and Alternative Energy Development Plan for 25% in 10 years (AEDP: 2012-2021)22. This roadmap (see Figure 7) aims to strengthen the country’s energy security by reducing the future use of fossil fuel and oil import. Although this plan will not cover the natural gas vehicles in the transport sector, the plan is geared to create integrated green communities, support the domestic renewable energy technology production industry, and to research, develop and promote Thailand’s renewable energy technology for competitive capability in the international market.

To implement the AEDP 2012-2021, the following six strategic issues are critical:

1. Promote community collaboration in producing and consuming renewable energy
2. Adjust incentive measures on relevant investments from the private sector
3. Amend the laws and regulations which do not benefit renewable energy development
4. Improve the infrastructure of transmission and power distribution lines, including a development towards a Smart Grid System
5. Build up public relations and comprehensive knowledge for the consumers
6. Promote research as a mechanism to develop the integrated renewable energy industry

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22 Renewable and Alternative Energy Development Plan for 25 Percent in 10 Years (AEDP 2012-2021)
Figure 7 presents Thailand’s AEDP 2012-2021 master plan on how power is going to be generated whereby 25% of the country’s total energy consumption will be supplied from renewable sources of energy. For solar energy, the target in 2021 is 2,000 MW with a current total generating capacity at 75.48 MW. Wind energy is targeted to generate 1,200 MW in 2021 from a present total generating capacity of 7.28 MW. Energy from hydropower is aimed to reach 1,608 MW in 2021, a huge increase from its current capacity of 86.39 MW (excluding the existing EGAT pumped storage system at Lam Takong units 1-2, each at 250 MW for a total of 500 MW). The projected energy from municipal solid waste (MSW) by 2021 will be 160 MW while its current total capacity is only 1.45 MW. For biomass energy, the 2021 target is 3,630 MW compared to its total current capacity of 1,752 MW. Biogas power on the other hand, is targeted to increase up to 600 MW from a total capacity of 138 MW at present.

The Department of Alternative Energy Development and Efficiency (DEDE) of Thailand’s Ministry of Energy did a study on new energy resources that could be tapped for electricity generation with an expected potential in commercial development for the future. Figure 7 shows that these new energy sources could be geothermal energy and ocean/tidal energy. From a current capacity of only 350 kW, geothermal energy is targeted in 2021 to increase to 1 MW, while new energy from ocean/tidal current is projected to reach 2 MW.

As for renewable energy for the transport sector (to substitute oil use), the AEDP 2012-2021 identifies specific targets for biofuel production of ethanol, biodiesel and other second-generation biofuel sources. Ethanol (as fuel to substitute benzene) production by 2021 is targeted to be 9 ML/day from a total current capacity of 1.3 ML/day. Biodiesel on the other hand, is projected to increase by 2021 from 5.97 ML/day from a total capacity of 1.62 ML/day at present. Production of energy from other biofuels for future diesel substitution is aimed at 25 ML/day by 2021 target.
An action plan (2012-2016) is in place to promote research on Future New Fuel for Diesel Substitution through a collaboration between the Ministry of Energy and the Ministry of Science and Technology. The integrated task includes the following exploratory activities:

- Jatropha: develop the jatropha variety for yielding high productivity, develop machinery for Jatropha cycle, and test the long-run operation of engine
- Seaweed-Algae: develop the varieties and commercial production
- FAEE: test its operation in cars and requiring the quality testing standard
- ED95: develop the additives and technology for modifying the old engine
- Diesohol: test for ethanol proportion appropriated to blend with diesel blended of 3-5% biodiesel and test the engine operation
- BHD: test its operation in engine and establish the quality testing standard
- BTL: produce at pilot scale to test its operation


The Ministry of Energy has developed a 20-year Energy Efficiency Development Plan (EEDP 2011-2030) to provide the national policy framework and guidelines on energy conservation implementation in the long term. This EEDP was formulated with a target to reduce energy intensity by 25% in 2030, compared with that in 2005. This target is equivalent to a reduction of final energy consumption by 20% in 2030 which is about 30,000 kilotons oil equivalent (ktoe). The main objectives of EEDP 2011-2030 are:

- To set the energy conservation targets in the short term (5 years) and long term (20 years), both at the national level and by energy-intensive economic sectors, i.e. transportation, industry, commercial and residential sectors;
- To lay down strategies and guidelines promoting energy conservation to achieve the set targets and to lay down measures and work plans to serve as the framework for concerned agencies in formulating their respective action plans for energy conservation promotion.

The strategic approaches and measures for EEDP 2011-2030 are summarised as follows:

(1) Mandatory Requirements via Rules, Regulations and Standard
- Mandatory energy efficiency labeling
- Enforcement of the Minimum Energy Performance Standards (MEPS) for equipment/appliances, buildings and vehicles
- Determination of the Energy Efficiency Resource Standards (EERS), or the minimum standards for large energy businesses

(2) Energy Conservation Promotion and Support
  • Execution of a “voluntary agreement”
  • Support and incentive provision
  • Promoting traveling by mass transit systems and goods transportation
  • Subsidisation for investment in the implementation of energy conservation measures
  • Support for the operation of ESCO companies, (e.g. the use of funding from the Energy Conservation Promotion Fund to increase credit lines given by the ESCO Fund)

(3) Public Awareness (PA) Creation and Behavioral Change
  • Public relations and provision of knowledge about energy conservation to the general public
  • Putting forth the concept and promoting activities related to the development of a low carbon society and low carbon economy
  • Determination of energy prices to reflect the actual costs and application of tax measures as an important tool

(4) Promotion of Technology Development and Innovation
  • Promotion of research and development
  • Promotion of demonstrations of energy-efficiency technologies

(5) Human Resources and Institutional Capability Development
  • Support for the development of professionals in the energy conservation field
  • Support for the development of institutional capability of agencies/organisations in both public and private sectors

1.4.2. Smart Grid Stakeholders in Thailand

To update today’s grid in Thailand, the following stakeholders are critical. These include government, local utilities, regulators, equipment manufacturers, appliance manufacturers and most importantly, customers. Once the idea to upgrade the grid has been approved, the country, involving regulators, utilities, vendors, legislators, research institutions, universities, and other stakeholders need to create a common vision and scope for the Smart Grid.

According to the World Economic Forum Report on “Accelerating Successful Smart Grid Pilots” (2010)24, Smart Grid Stakeholders include the national policy makers, regulators, utility companies, vendors, the academe and non-government organisations (NGOs) as well as the customers. The national policy makers are responsible for developing the country’s master plan and other supporting policies for Smart Grid development. In Thailand, this constitutes the Energy Policy and Planning Office of the Ministry of Energy. The regulators are important in setting the regulatory framework and the implementation guidelines and standardisation. In Thailand, the Energy Regulatory Commission is in charge as the regulator. The utility companies must ensure a Smart Grid development that is in line with the national master plan and regulatory framework. The Electricity Generating Authority of Thailand, Provincial Electricity Authority, and Metropolitan Electricity Authority are the key utilities in Thailand. The vendors would be the solution providers for the Energy Management System (EMS) integration service. The academe and NGOs will play an important role in the research, development and demonstration (RD & D) collaboration of stakeholders, while the consumer will actively get involved in generating active demand responses to the Smart Grid. The relationship among Smart Grid key stakeholders is illustrated in Figure 8.

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24 Accelerating Successful Smart Grid Pilots, World Economic Forum Report 2010
The Thailand Smart Grid Subcommittee structure is shown in Figure 9. The subcommittee on the study of National Smart Grid Development Master Plan is under the National Energy Policy Council (NEPC). EPPO is equally responsible in developing this master plan. The working groups include Thailand’s three utilities, i.e. EGAT, PEA and MEA.
There are six agencies in Thailand that serve as key stakeholders in the development and deployment of Smart Grid in the country. The role of each agency and their Smart Grid plans are provided hereafter.

A. Energy Policy and Planning Office (EPPO), Ministry of Energy

The Energy Policy and Planning Office is a pivotal agency under the Ministry of Energy, being tasked with the development of national energy policies and planning, including measures to manage and administer the energy sector, with due consideration of economic and social development, concurrently with environmental protection. In order to undertake the mentioned tasks, it is crucial to acquire substantial information and data for analysis and development of recommendation on energy issues to be presented to the management. EPPO, therefore, has developed an energy statistics database system with a view to following up both national and global energy situations.

EPPO is entrusted with the following six missions:

1. Recommend energy policies and integrate/review energy management plans of the country;
2. Recommend national strategies for energy conservation and alternative energy promotion;
3. Recommend measures to solve and prevent oil shortage in both short and long terms;
4. Supervise, monitor and evaluate the effectiveness of national energy policy and energy management plans;
(5) Administer the information and communication technology (ICT) with regard to energy issues of the country; and
(6) Enhance EPPO to become a strategic organisation.

The Ministry of Energy appointed the Subcommittee on the Study of National Smart Grid Development Master Plan on December 8, 2011. The master plan of Thailand Smart Grid Development for the next 20 years (until 2030) is being prepared by EPPO.

The policy plan for Smart Grid development identifying specific problems, key drivers of change and specifying important current energy policies is shown in Figure 10. For the Smart Grid development to move forward, the key factors that will drive this change are:

- Transition to low carbon economy
- Development of power system and Power Trade in ASEAN Power Grid for power system security and increasing electricity demand
- Transition to Electric Vehicles
- Need of energy efficiency development to reduce operating cost in manufacturing sector
- Economic growth
- Decentralised power generation

![Figure 10. Policy Plan for Smart Grid Development: Problems and Key Drivers](Source: Thailand Smart Grid Development)
The short-term, medium-term and long-term policy plans for Smart Grid development in Thailand is presented in Figure 11. The short-term plan constitutes the initial formulation of Smart Grid policies that chart out specific strategies and roadmaps by the various stakeholders. In the medium-term, Smart grid research and deployment are intensified along with public participation and understanding. Pilot investments on Smart Grid deployment will also be enhanced at this stage. The long-term goal is to fully develop and deploy Smart Grid for the whole Thailand.

The pilot project for Smart Grid deployment by the EPPO is illustrated in Figure 12. This pilot project on Smart Micro Grid is aimed at testing strategies to:

- Improve power transmission and distribution constraints
- Enhance the efficiency of distributed generation
- Control of power flow from distributed generation to the nearest load
- Stabilise the operation of power system while connecting with distributed generation
The Electricity Generating Authority of Thailand (EGAT)

The Electricity Generating Authority of Thailand was established on May 1, 1969 by the promulgation of the Electricity Generating Authority of Thailand Act B.E. 2511 which merged assets and operations of three previous state enterprises, namely Yanhee Electricity Authority, Lignite Authority and Northeast Electricity Authority. EGAT is presently a state enterprise under the Ministry of Energy that builds, owns and operates several types and sizes of power plants across the country. It has a combined installed capacity of 13,617.10 MW, accounting for about 47.8% of the country’s 28,479.00 MW generating capacity. EGAT also purchases electric power from private power companies and neighboring countries.

The EGAT Smart Grid Roadmap was proposed to the Smart Grid Working Group (EPPO, EGAT, PEA, MEA) on November 20, 2012. Their roadmap has three components namely, the Smarter Grid, Green Grid, and Sustainable Grid as shown in Figure 13.
The EGAT Smart Grid concept including the Smart Grid driving forces, key Smart Grid characteristics and key EGAT functions is presented in Figure 14. EGAT’s primary mission for the Thailand’s Smart Grid context is shown in Figure 15.
Figure 15. EGAT’s Primary Mission for Smart Grid Context
(Source: EGAT Smart Grid Roadmap)

EGAT’s Primary Mission for Smart Grid Context

Specific targets have been set for each Smart Grid component over the period of 2013 to 2032. The phases comprise the following:

- Phase I: 2013 – 2017 - Foundation and Framework Development
- Phase II: 2018 – 2022 - Pilot and Backbone Implementation
- Phase III: 2023 – 2027 - Deployment and Assessment
- Phase IV: 2028 – 2032 - Full Scale Integration

EGAT has laid out five key strategies in order to achieve these targets. These are as follows:

1. Enhanced ASEAN Power Grid

   The goal is for energy cooperation among neighboring countries where the allocation and consumption of available regional energy resources is brought to maximum benefit. EGAT also aims to observe, control, and protect the power system through remote control to maintain its reliability, stability and security. Therefore it is strategic to:

   - Pursue the economic value added of the ASEAN Power Grid/Great Mekong Subregion-Regional Power Trade Coordination Centre (APG/GMS-RPCC); and
   - Develop and use the Wide Area Protection and Control (WAPC).
(2) Integrated Information and Communications Technology (ICT)

The goal is to improve the structure of EGAT’s organisation communication and information system to support the development of Smart Grid in Thailand and ASEAN. An integrated ICT will implement EGAT Smart Grid’s communications that works with efficiency, stability, and security. EGAT aims to develop the internet connection of all equipment, including all sensors involved in EGAT’s generation and transmission systems. Additionally, it would be critical to develop the Thailand Smart Grid into a national network by standardising network connection among EGAT, PEA and MEA. Therefore, the specific strategies are:

- Restructure EGAT’s organisation concerned with communication and information system to support Smart Grid
- Update the traffic management system in EGAT’s communication to guarantee the quality of service and data integrity
- Enhance internet technology equipment and instrument and develop internet protocols to facilitate data exchange; and
- Standardise the network connection among EGAT, PEA, and MEA.

(3) Smart Operation

To develop into a Smart Operation, it is important to improve existing substations and construct new substations in accordance with international standard, which affects the performance and reliability of the power system. It is also essential to increase the ability of the control centre in real and reactive power control to manage the energy and to ensure the balance of power within the area maintaining the voltage stability and reducing power loss in the transmission system. In a Smart Operation, it is vital to monitor and estimate the performance and lifetime of the devices in both generation and transmission systems used in the Asset Management of EGAT.
**Figure 16. EGAT's Smart Grid Plan**
(Source: EGAT Smart Grid Roadmap)
Therefore, the key strategies for a Smart Operation are the following:

- Renovation of the substations to be substation automation – IEC61850;
- Application of Supervisory Control and Data Acquisition (SCADA) and Energy Management System in regional control centres; and
- Development of automatic monitoring system and lifetime estimation of the devices in the generation and transmission system.

(4) Enabling Demand Response

In a successful Smart Grid system, it is critical to forecast demand accurately and handle the fluctuations. A key step is to standardise the automatic meter reading including sending data to the control centre, which allows for estimation of the energy demand in real-time and to make the decision of EGAT generation better. Enabling demand response will serve to balance between supply and demand, and also to reduce power consumption by Real Time Pricing (RTP) or Time of Use (TOU) electricity price, especially during the period of peak demand. Therefore, key strategies to achieve these are the following:

- Establishment of a demand forecast centre;
- Standardisation of data from the automatic meter reading with the PEA and MEA; and
- Development of the Demand Response with the PEA and MEA.

(5) Green Supply Portfolio

To enhance the green supply portfolio of Thailand, EGAT aims to support the policy of increasing the renewable energy power plants in EGAT’s system in accordance with the government policy (AEDP 2012-2021). In a Smart Grid system, it is important to be able to forecast power generation potentials and send back information to the data processing centre for forecasting the power generation and consumption of the power network. It is also imperative to develop an energy storage system for handling the uncertainty of renewable energy generation and to develop a smart charging technology to avoid overloading the EGAT’s system from electric vehicle (EV) charging. These objectives entail the following strategies:

- Construction of small renewable energy, such as small hydro, solar, and wind.
- Establishment of the grid code for renewable energy power plant
- Development of monitoring and forecasting system of the renewable energy power plants
- Development of energy storage system to handle the generation of renewable energy and reducing the electricity demand; and
- Development of charging technology to support the Electric Vehicles (EV) and V2G technology.
C. Provincial Electricity Authority (PEA)

The Provincial Electricity Authority is a government enterprise under the Ministry of Interior. The PEA's responsibility is primarily concerned with the generation, distribution, sales and provision of electric energy services to the business and industrial sectors as well as to the general public in provincial areas, with the exception of Bangkok, Nonthaburi and Samut Prakran provinces. The PEA has expanded electricity supply to all areas covering 73 provinces, approximately 510,000 km², accounting for 99% of the country's total area.

The PEA is guided by a policy that covers six main areas, which are stated as follows:

1. Focusing on the organisation's value added, securing financial status and sustainable growth by continuous improvement of the management process. Best utilisation of available resources as well as seeking for investment and business development opportunities both national and international levels, through business partnership channel and investment expansion among affiliated companies.

2. Aiming to be a Customer-Centric Organisation by establishing and developing good customer relations to meet customer's need and satisfaction as well as good performance in providing creativity, innovation and application of high-technology.

3. Continuous development of electricity infrastructure in order to enhance quality of life and competence according to the national government policy. Development of potential Smart Grid, which can serve adequate electricity power and efficient investment as well as security and universal reliability.

4. Promotion of alternative energy, renewable energy and efficient energy consumption to counter the global warming crisis and being a government mechanism to drive and support for restructuring of the national economy to Green Economy in the future.

5. Aiming to be a Live Organisation which focuses on development of human resources and intellect resources, promotion of learning and knowledge management, prioritising on staffs' quality of life as well as potential development to eventually improve the efficiency of work and meet the ultimate goals of the organisation.

6. Application of Good Governance principle as key driving force of the organisation, along with Corporate Social Responsibility (CSR) for stable and sustainable growth.

The PEA Smart Grid will utilise ICT to manage, monitor and control the generation, transmission and distribution of electrical energy. According to the PEA Smart Grid Roadmap²⁶ distributed generation from alternative clean sources is enabled, while asset utilisation with new management system is maximised. It also enables the use of electric vehicles and provides connection services to the electrical network through smart metering. The Smart Grid roadmap drawn by the PEA is aimed to provide efficiency, safety, reliability and international standards of power quality to meet customer needs in the 21st century.

²⁶ PEA Smart Grid Roadmap (Draft)
Figure 17 illustrates PEA’s Smart Grids concept, which envisions the electrical world of the future to improve the quality of life while maintaining the environment. The PEA Smart Grids will lead to Smart Energy (efficient use and generation of energy), Smart Life (improve quality of life) and a Smart Community (intelligent and green community in the future).

Figure 17. PEA's Smart Grid Concept  
(Source: PEA Smart Grid Roadmap)

Smart Energy means a clean, secure, and safe energy that have high quality and continuity of service. This considers a future where use of clean and renewable energy is increased as GHG emitting fossil fuels run out. It envisions an increase in electricity use due to its high efficiency and variety of fuel sources for electricity generation. Smart Energy also means ICT is utilised for energy management to achieve a secure, environment-friendly and highly efficient generation, transmission, distribution and consumption of energy.

The benefits of using Smart Energy are:

- Energy management efficiency;
- Improve electrical system and quality of service for customers;
- Increase portion of clean and renewable energy use to reduce greenhouse gases;
- Postpone a large construction plants and reduce a cost of imported energy;
- A secure electrical system reducing a number of outage and its duration.
Smart Life implies the ability for power users to participate in the management of electricity supply to match their lifestyles. Power users have the option to generate electricity (Prosumer) and use electronic appliances to improve their quality of life at work and home. In the future, power users will have sufficient information for managing their energy use more efficiently and have the option to generate and sell electricity back to PEA. There will be a choice of electric vehicles (EVs) for transportation by which electricity can be stored in the battery for emergency use or sold back to PEA when price increases. Consumers will have a choice of intelligent appliances to improve quality of life which can be controlled remotely and they can request for electricity use at any time through internet facilities. Smart Life will lead to the following benefits:

- Consumers can manage their energy use at home or work more efficiently and can reduce their cost of electricity;
- Consumers can have profit from selling back electricity and choose a variety of services using the internet.

Smart Community denotes an intelligent and green community consisting of households, businesses, and industry with respect to energy usage and environment. This future community will increase electricity uses for transportation systems such as personal EVs, bus or train systems. There will be an increase in the number of charging stations in public areas such as apartments, parking lots, department stores or public highways. Even the management of waste and wastewater will be more efficient through the generation of electricity from waste and a reduction in greenhouse gases from electricity generation and transportation. The benefits of a Smart Community are:

- Power users and business sectors can rely on fast and high quality of service from public charging stations;
- Transportation cost can be reduced while enjoying a clean environment.

Table 2 summarises the PEA Smart Grid plan for each component in three stages: Stage 1 (2012-2016) is the planning and pilot project, Stage 2 (2017-2021) refers to the large-scale expansion and the Stage 3 (2022-2026) as the optimal stage.

Pilot projects under the PEA Smart Grid development are described in more details in Tables 3 to 7.
### Table 2: PEA Smart Grid: Three Components

<table>
<thead>
<tr>
<th>Smart Energy</th>
<th>Stage 1:</th>
<th>Stage 2:</th>
<th>Stage 3:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning and Pilot project (2012-2016)</td>
<td>Large Scale Expansion (2017-2021)</td>
<td>Optimal Stage (2022-2026)</td>
<td></td>
</tr>
<tr>
<td>Electricity networks in 4 cities with automated system</td>
<td>Asset Management optimisation</td>
<td>Automated electricity networks nationwide/ self-healing feature enabled</td>
<td></td>
</tr>
<tr>
<td>Network supports of Distributed Generation</td>
<td>Completion of Mobile Workforce Management (MWM)</td>
<td>Network integrated with a large renewable energy resources</td>
<td></td>
</tr>
<tr>
<td>Microgrids (Community Power Networks)</td>
<td>Completion of automation substation</td>
<td>Cyber security system adequate</td>
<td></td>
</tr>
<tr>
<td>Electricity Storage</td>
<td>Expand fully automated network covering major cities across the country</td>
<td>The balance and forecast system production and energy utilisation</td>
<td></td>
</tr>
<tr>
<td>The integration of Enterprise system</td>
<td>The development of renewable energy sources and energy storage</td>
<td>Virtual power plants created</td>
<td></td>
</tr>
<tr>
<td>Mobile work force in 4 cities</td>
<td>AMI development completion</td>
<td>Power users can buy or sell electricity in real time</td>
<td></td>
</tr>
<tr>
<td>Networks supports of Distributed Generation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Smart Life</th>
<th>Stage 1:</th>
<th>Stage 2:</th>
<th>Stage 3:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart meter infrastructure (AMI) completion in central region and 10 other large cities</td>
<td>Energy management completion in all large/medium cities</td>
<td>Users can choose to buy electricity from different suppliers</td>
<td></td>
</tr>
<tr>
<td>Smart &amp; Green PEA Completion in 216 offices</td>
<td>The system provides power usage information via the internet (Virtual office)</td>
<td>Energy management optimisation</td>
<td></td>
</tr>
<tr>
<td>Demand response management</td>
<td>Domestic consumers can produce their own electricity; surpluses can be sold to the utility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public charging station</td>
<td>Home/building energy management automation reduces electricity bills</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The extensive use of electric transportation</td>
<td>Intelligent electric vehicle changing optimisation to reduce peak demand</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Smart Community</th>
<th>Stage 1:</th>
<th>Stage 2:</th>
<th>Stage 3:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy savings for public street and community lighting</td>
<td>Pervasive intelligent public street and community lighting</td>
<td>Two ways power supply of electric vehicles (vehicle to grid-V2G)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bundled services with other utilities (common billing, etc.)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 3: Smart Grid Development Project Phase 1

<table>
<thead>
<tr>
<th>1. Implementation Period</th>
<th>Year 2013 – 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Objective</td>
<td>To develop the PEA conventional grid to become PEA Smart Grid which will be more stable, smart, security and to be as a pilot for future development in other areas</td>
</tr>
<tr>
<td>3. Project Area</td>
<td>Pattaya City, Chonburi Province; Muang Chiangmai District, Chiang Mai province; Muang Nakhon Ratchasima District, Nakhon Ratchasima province; and Muang Phuket District, Phuket province</td>
</tr>
<tr>
<td>4. Scope of Work</td>
<td>Items</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Energy Storage (set)</td>
<td>3</td>
</tr>
<tr>
<td>2. Smart Power Maintenance Vehicle (Vehicle)</td>
<td>4</td>
</tr>
<tr>
<td>3. Solar Energy Rooftop (set)</td>
<td>6</td>
</tr>
<tr>
<td>4. Advanced Meter Infrastructure Installation - 1 Phase (Meter)</td>
<td>120,000</td>
</tr>
<tr>
<td>5. Advanced Meter Infrastructure Installation - 3 Phase (Meter)</td>
<td>6,700</td>
</tr>
<tr>
<td>6. Public Electric Vehicle Charging Station (station)</td>
<td>6</td>
</tr>
<tr>
<td>7. Last Mile and Sensor (IEDs) System Installation at Transformer (set)</td>
<td>792</td>
</tr>
<tr>
<td>8. Smart Substation System Installation (set)</td>
<td>7</td>
</tr>
<tr>
<td>9. Fiber Optic Installation (km.)</td>
<td>430</td>
</tr>
<tr>
<td>10. Computer Data Centre System (set)</td>
<td>-</td>
</tr>
</tbody>
</table>
### 5. Budget (Million Thai Baht)

<table>
<thead>
<tr>
<th></th>
<th>950</th>
<th>820</th>
<th>1,000</th>
<th>790</th>
<th>85</th>
<th>3,645</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic Loan</td>
<td>320</td>
<td>270</td>
<td>335</td>
<td>260</td>
<td>30</td>
<td>1,215</td>
</tr>
<tr>
<td>PEA Income</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,270</td>
<td>1,090</td>
<td>1,335</td>
<td>1,050</td>
<td>115</td>
<td>4,860</td>
</tr>
</tbody>
</table>

### 6. Benefit

1. To enhance the power system management to be more reliability and better responsive to customer demand and demand response management which will delay the decision of new power plant instruction.
2. To support the increasing source of renewable energy, this will reduce the need on conventional power plant construction with high environmental impacts.
3. To support and promote the use of electric vehicle, this will be less polluted and reduce the imported power.
4. To promote industrial sectors to develop technologies/equipments to support the smart grid system, this will also create job opportunities in the country.
5. To reduce greenhouse gas emission from transportation and power generation sectors by developing the four pilot cities as Low Carbon Community.
Table 4: Advanced Metering Infrastructure Development Project Phase 1

1. Implementation Period
   Year 2014 - 2018

2. Objective
   To develop Advanced Metering Infrastructure project as a crucial component of Smart Grid system with Smart Meter and other relevant systems.

3. Project Area
   26 municipalities in PEA service area

4. Scope of Work

<table>
<thead>
<tr>
<th>Items</th>
<th>Region</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1. Advanced Meter Infrastructure Installation - 1 Phase (Meter)</td>
<td>242,000</td>
<td>77,000</td>
</tr>
<tr>
<td>2. Advanced Meter Infrastructure Installation - 3 Phase (Meter)</td>
<td>30,000</td>
<td>15,000</td>
</tr>
<tr>
<td>3. Last Mile Installation (set)</td>
<td>2,225</td>
<td>880</td>
</tr>
<tr>
<td>4. Fiber Optic Installation (km.)</td>
<td>500</td>
<td>110</td>
</tr>
<tr>
<td>5. Computer Data Centre System (set)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

5. Budget (Million Thai Baht)

<table>
<thead>
<tr>
<th>Items</th>
<th>Region</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>- Domestic Loan</td>
<td>1,035</td>
<td>370</td>
</tr>
<tr>
<td>- PEA Income</td>
<td>350</td>
<td>125</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,385</strong></td>
<td><strong>495</strong></td>
</tr>
</tbody>
</table>

6. Benefit

1. Reduce the cost of conventional meter reading
2. Reduce the income lost from Non-Technical Loss and Technical Loss
3. Create Peak Shaving by encouraging customer behavior change to use more electricity during off-peak and reduce the cost during Peak demand
4. Load Profile data can be used for power distribution planning, maintenance and planning of substation construction and additional transformer installation
5. Customers will feel confident with the accuracy of meter reading and will be able to check their electricity consumption information.
### Table 5: Micro Grid Development Project in Koh Kood and Koh Maak, Trad Province

<table>
<thead>
<tr>
<th>1. Implementation Period</th>
<th>Year 2014 - 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Objective</td>
<td>To develop efficient power generating system in remote area and seek energy sources for remote area with inadequate power, this is also to reduce investment on peak load management. To serve as piloting of Microgrid system. To increase renewable energy generation in accordance with the government policy.</td>
</tr>
<tr>
<td>3. Project Area</td>
<td>Koh Kood and Koh Maak, Trad Province</td>
</tr>
<tr>
<td>4. Scope of Work</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Items</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Koh Kood</td>
<td>- Solar PV Plant Installation (set)</td>
</tr>
<tr>
<td></td>
<td>- Hydro Power Plan Installation (set)</td>
</tr>
<tr>
<td></td>
<td>- Energy Storage Installation (set)</td>
</tr>
<tr>
<td>2. Koh Maak</td>
<td>- Solar PV Plant Installation (set)</td>
</tr>
<tr>
<td></td>
<td>- Energy Storage Installation (set)</td>
</tr>
<tr>
<td>5. Budget (Million Thai Baht)</td>
<td>- Domestic Loan</td>
</tr>
<tr>
<td></td>
<td>- PEA Income</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
</tr>
<tr>
<td></td>
<td>2. Reduce the capital cost of diesel power generation where PEA has to supply to remote island area.</td>
</tr>
<tr>
<td></td>
<td>3. Reduce the greenhouse gas emission that leading to global warming</td>
</tr>
</tbody>
</table>
Table 6: Micro-Grid Development in Mae Sareang, Mae Hongson Province

1. **Implementation Period**  
   Year 2014 - 2018

2. **Objective**  
   To develop generation and distribution system in the project area efficiently and reliably. To provide energy sources for remote area with inadequate power supply. To reduce loss from a long transmission and distribution line. To develop the power system in the area to support Smart Grid system. To increase renewable energy generation in accordance with the government policy. To reduce greenhouse gas emission. To reduce carbon dioxide emission.

3. **Project Area**  
   Mae Sareang District, Mae Hongson Province

4. **Scope of Work**  
<table>
<thead>
<tr>
<th>Items</th>
<th>Region</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Distribution Energy Storage System, DESS – Pumped Hydro Type (set)</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>2. Energy Storage Installation (set)</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>3. Micro-Grid Controller Installation (set)</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>

5. **Budget (Million Thai Baht)**  
<table>
<thead>
<tr>
<th></th>
<th>Domestic Loan</th>
<th>PEA Income</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>245</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>85</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>330</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

6. **Benefit**  
   1. Micro-Grid system has been developed and be able to support Smart Grid system in Mae Sareang District, Mae Hongson Province
   2. Power generation and distribution system with high efficiency and reliability
   3. Reduce the capital cost of diesel power generation where PEA has to supply to remote island area.
   4. Reduce transmission and distribution loss
   5. Reduce the greenhouse gas emission that leading to global warming
Table 7: Power System Improvement Plan for Very Small Power Producer of Renewable Energy

<table>
<thead>
<tr>
<th>1. Implementation Period</th>
<th>Year 2014 - 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Objective</td>
<td>To develop power system interconnection with VSPP. To improve power quality from VSPP interconnection.</td>
</tr>
<tr>
<td>3. Project Area</td>
<td>All over the country</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4. Scope of Work</th>
<th>Items</th>
<th>Region</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. 22 kV and 33 kV Distribution Line Construction (cct-km)</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>2. UHF Remote Radio and FRTU Installation (set)</td>
<td>120</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>3. Voltage Potential Improvement with Equipment (set)</td>
<td>11</td>
<td>19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5. Budget (Million Thai Baht)</th>
<th>Items</th>
<th>Region</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Domestic Loan</td>
<td>545</td>
<td>555</td>
</tr>
<tr>
<td></td>
<td>- PEA Income</td>
<td>185</td>
<td>185</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>730</td>
<td>740</td>
</tr>
</tbody>
</table>

| 6. Benefit                   | 1. Efficient power system interconnection with VSPP |
|                             | 2. Reduce impacts to power system from the VSPP interconnection. |
D. Metropolitan Electricity Authority (MEA)

The Metropolitan Electricity Authority is a government enterprise under the Ministry of Interior. Established in 1958, this organisation was responsible for generating and selling electrical power in the metropolitan area until 1961, when the generating aspect was transferred to EGAT. MEA provides high-class service while laying emphasis on sustainable growth of related business as well as responsibility for the society and the environment.

MEA's missions are:

(1) To develop towards a high performance organisation with efficient management systems based on participation of all stakeholders while adhering to a strong commitment to the Principles of Good Corporate Governance, promoting the organisation's positive image and taking responsibility for the society and the environment;

(2) To conduct electricity business in pursuit of sustainable growth with qualified, reliable and safe power distribution system as well as high class service; and

(3) To promote sustainable growth of related business that is promising and has the potential for growth.

MEA also performs its development in conformity with the Statement of Direction which is the goal of the public sector and development directions of the country. Its goals are as follows:

- Ensure the efficiency of operating cost management compliance with industry standards;
- Develop and expand the power distribution system to meet high quality and cope with the increasing power demand with purpose to enhance competitive advantages of the country;
- Oversee community security and enhance a nice landscape;
- Focus on increasing value added to the organisation by means of maximising the utilisation of assets for utmost benefits and expanding related business for strengthening performance and financial status in preparedness for future competition including generating sustainable revenue for the Government;
- Support resource conservation together with economic and efficient use of energy;
- Initiate measures to enhance customer satisfaction.

Table 8 presents the MEA Smart Grid objectives consisting of three themes namely, Power System, Services, and Energy Saving and Renewable Energy. The MEA Smart Grid roadmap details are provided in Table 9, specifically for the distribution system and customer components of a Smart Grid. It covers four different stages (initiation, integration, deployment and the ultimate stage) over the projected period of implementation from 2012 to 2051.

On the other hand, the MEA Automation System consisting of the Energy Management System (EMS), Substation Automation (SA), and Distribution Management System (DMS) is illustrated in Figure 18.
### Table 8: MEA Smart Grid Objectives

<table>
<thead>
<tr>
<th>Theme</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power System</td>
<td>Service Reliability</td>
</tr>
<tr>
<td></td>
<td>Operating Efficiencies and Economics</td>
</tr>
<tr>
<td></td>
<td>Security</td>
</tr>
<tr>
<td>Services</td>
<td>More Services Opportunity</td>
</tr>
<tr>
<td></td>
<td>More Interaction between MEA and Customers</td>
</tr>
<tr>
<td>Energy Saving and Renewable Energy</td>
<td>Provide infrastructure to integrate renewable resources</td>
</tr>
<tr>
<td></td>
<td>Promote Energy Efficiency</td>
</tr>
<tr>
<td></td>
<td>Research and Support the integration of EV</td>
</tr>
<tr>
<td></td>
<td>Research and Support the integration of Energy Storage</td>
</tr>
</tbody>
</table>

(Source: MEA Smart Grid Roadmap)

### Table 9: MEA Smart Grid Plan

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution System</td>
<td>• Substation Automation • Advanced Metering Infrastructure • Energy Management System • Distribution Management System</td>
<td>• Optimised Asset Management • Optimised Model Workforce Management • Fully Substation Automation • Distribution Generation • Multiple Tariff Structures • Self Generation • Outage Management • Transformer Load Management</td>
<td>• Large Scale Renewables • Urban Smart Micro Grids • Intelligent Building • Smart Application • Wide Spread Renewables</td>
<td>• Self Healing Grid • Full Automation • Pervasive Cyber Security • Full Customer Choice • Competitive Market • Demand Side Management</td>
</tr>
<tr>
<td>Customer</td>
<td>• Piloting Electric Vehicles • Intelligent Street-lights</td>
<td>• Potential Charging Infrastructure • Development of Renewable • Hybrids and Full EV’s • Customer Portal</td>
<td>• Fully Charging Station • Energy Storage</td>
<td>• Electric Vehicles as a distributed resource (V2G VPP)</td>
</tr>
</tbody>
</table>

(Source: MEA Smart Grid Roadmap (Draft))
E. Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy

The Department of Alternative Energy Development and Efficiency of the Ministry of Energy, has the mission to support and promote the clean energy production and consumption from sources consistent with the situation of each area that is cost effective and sustainable. It aims to develop clean energy technologies commercially for both domestic consumption and export, including creating co-operation networks that will lead Thailand to an energy knowledge base society so that the country's economy will be secure and its people will live in social harmony and sustainable happiness.

The duties of DEDE prescribed under the Act on Administrative Organisation of the State Affairs are:

- To be responsible for energy efficiency promotion, energy conservation regulation, energy sources provision and alternative development of integrated energy uses;
- Energy technology dissemination in a systematic and continuous manner to adequately respond to the demand from every sector at optimal costs.

The main duty of DEDE as prescribed under the Energy Conservation Promotion Act B.E.2535 is to be responsible for regulation, supervision, promotion and assistance provision to the designated factories and buildings to comply with laws and regulations for efficient use of energy and savings. Once the Thailand Smart Grid Master Plan developed by EPPO is available, DEDE will be one of the key stakeholders particularly on alternative energy generation and development to be in line and to support the Smart Grid infrastructure of Thailand.
F. Energy Regulatory Commission (ERC) of Thailand

Thailand’s Energy Regulatory Commission was appointed by His Majesty King Bhumibol Adulyadej as an independent regulatory agency. The foundation of all functions and responsibilities follows the enactment of the Energy Industry Act B.E. 2550 (2007). ERC consists of seven commissioners and aims to work independently and separately from policy framework to ensure the equality and fairness nested between consumers, producers, and other relevant interest groups. The primary functions and duties are to oversee the regulations that deal with electricity systems of generation, transmission, distribution, and their system operator. In particular, ERC’s main objectives consist of monitoring energy market conditions by tariff review, licensing, approval of power purchase, dispute settlement and fulfilling its mandate, in order to counterbalance each other, to ensure maximum interests of the people and the country.

ERC’s mission is to regulate the energy industry operation so as to establish an energy system that is reliable, efficient and fair for both energy consumers and energy suppliers and that is environmental-friendly, by adhering to fair and transparent execution of defined duties and responsibilities for the benefit of sustainable development of the country in the social, economic and environmental aspects.

ERC appointed their internal Smart Grid working group to prepare the ERC Smart Grid Roadmap. The main objective is to develop Smart Grid Regulatory Framework in regulating and supporting the Smart Grid development and implementation in Thailand. This Regulatory Framework will be in accordance with the Smart Grid Strategies and Objectives in Thailand’s Smart Grid Master Plan developed by EPPO.
PART II
SMART GRID TECHNOLOGIES
PART II

SMART GRID TECHNOLOGIES
The Smart Grid is a network of networks comprising many systems and subsystems. That is, many systems with various ownership and management boundaries interconnect to provide end-to-end services between and among stakeholders as well as between and among intelligent devices. This section aims to present in detail the components and various existing technologies that are essential in the development and deployment of Smart Grid systems.

Figure 19 is an illustration of information networks where Smart Grid control and data messages are exchanged. Clouds are used to illustrate networks handling two-way communications between devices and applications. The devices and applications are represented by the boxes and belong to the seven different domains: Customer, Generation, Transmission, Distribution, Operations, Markets, and Service Provider.28

Applications and devices in the Transmission or Distribution domain include phasor measurement units (PMUs) in a transmission line substation, substation controllers, distributed generation, and energy storage. Applications and devices in the Operations domain include Supervisory Control and Data Acquisition (SCADA) systems and computers or display systems at the operation centre. While SCADA systems may have different communication characteristics, other computer applications in the Operations, Markets, and Service Provider domains are similar to those in Web and business information processing, and their networking function may not be distinguishable from normal information processing networks.

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28 NIST Resource 2.0
2.1. COMPONENTS OF A SMART GRID

In Figure 19, each domain-labeled network (for example, “Transmission”, “Generation”, “Distribution” and “Customer”) is a unique distributed-computing environment and may have its own sub-networks to meet any domain-specific communication requirements. The physical or logical links within and between these networks, and the links to the network end points, could utilise any appropriate communication technology either currently available or developed and standardised in the future.

Within each network, a hierarchical structure consisting of multiple network types may be implemented. Some of the network types that may be involved are Home Area Networks, Personal Area Networks, Wireless Access Networks, Local Area Networks, and Wide Area Networks. On the basis of Smart Grid functional requirements, the network should provide the capability to enable an application in a particular domain to communicate with an application in any other domain over the information network, with proper management control of all appropriate parameters (e.g. Who can be interconnected? Where? When? How?). Many communication network requirements need to be met including data management control, as well as network management such as configuration, monitoring, fault detection, fault isolation, addressability, service discovery, routing, quality of service, and security. Network security is a critical requirement to ensure that the confidentiality, integrity, and availability of Smart Grid information, control systems, and related information systems are properly protected. It may be necessary for regional networks, such as Network A and Network B in Figure 19, to have interconnections. There is a need for international networks to connect between either the Nationwide Network or the regional networks, to meet the requirements that enable international power flows such as between European countries.

Figure 20 further shows interrelationships among the different sectors. The components of the Smart Grid Technology namely, Generation, Transmission, Distribution, and Customer Sector are described in more detail hereafter. This will be followed by discussions on Renewable Energy Technology (RET) integration and Wireless Technology.  

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29 Regulatory Aspects of Smart Metering: US Practice, Public Service Commission of Wisconsin, Powerpoint presentation at Sarajevo, Bosnia-Herzegovina, September 2010
2.2. SMART POWER GENERATION

Smart Power Generation (SPG) is defined as resource capacity having high operational flexibility, high energy efficiency, and diverse fuel capability. Operational flexibility requires generation to have multiple dynamic operation modes, from ultra-fast grid reserve to efficient base load generation. SPG has fast start-up, shut-down, and load ramps with agile dispatch and is able to supply power in megawatts to the electricity grid within 1 minute and full power in 5-10 minutes. Ideally, SPG should be suitable for base load generation, peaking, and balancing requirements and have independent operation of multiple units with remote operation for off-site control. SPG should be capable of being situated within or near load pockets and have low maintenance costs regardless of operation method including some sort of grid black-start capability. SPG should be energy efficient with sustainable and affordable power systems requiring the highest level of simple-cycle energy efficiency available. Characteristics of SPG include high efficiency in a wide load range, from almost zero load to full load, low water consumption, and low CO2 emissions regardless of operation method, expandable plant size for future plant size optimisation and high reliability and availability through multiple parallel units.

Electricity grids face a variety of trends which impact current and future markets and operations. Increased penetration of variable renewable energy production creates the need for more ancillary services to smooth fluctuations in renewable output and to provide for forecast errors in those outputs. Thermal plant retirements and environmental restrictions impact resource adequacy. Resources such as Demand Response (DR), distributed resources and new storage and

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Figure 20. Interrelationship of the Different Sectors
(Source: "Regulatory Aspects of Smart Metering: US Practice, Public Service Commission of Wisconsin, Powerpoint presentation at Sarajevo, Bosnia-Herzegovina, September 2010)
communication technologies create uncertainties in how these important new resources interact with one another. Lastly, new resources can create changing power flows and import/export transfers between balancing authority which creates uncertainties with network and/or grid expansion.

2.2.1 Renewable Energy Technologies

Most renewable electricity technology (RET) sources from wind, solar radiation and biomass have properties that make them less attractive from an availability and flexibility point of view, at least compared with traditional power plants. It is therefore crucial to develop smart power generation and distribution facilities that can support electricity generation from renewable sources. Such smart power generation units have to make optimum use of the available fuel resources at possibly minimum costs and minimum impact on the environment. Discussions below will focus on the opportunities and challenges brought about by RET on Smart Grid.

A. Solar Energy

The potential for generation of electricity from sunlight is enormous, able to provide all the total worldwide energy needed multiple times over 79 – although it currently provides only 0.01% of total energy consumption 31. Generation can occur through direct powering with photovoltaic (PV) devices or indirectly, through concentrating solar power (CSP), in which heat from the sun is used to boil water, which is then used in power plants. While sometimes used for off-grid energy production, including small solar water heaters, most solar applications are now interconnected to the grid. Grid-connected solar PV continues to be the fastest growing power generation technology.

The largest solar power plants, such as the 354 MW Solar Energy Generating Systems in the Mojave Desert in California, USA are concentrating solar thermal plants. Nonetheless, with recent technological developments, multi-megawatt photovoltaic plants have been built such as: (1) the 60 MW Omedilla plant built in Spain in 2008; (2) the 54 MW solar park in Strass kirchen, Germany; and (3) the 46 MW Moura station in Portugal. Building on its success in developing wind farms, Germany became the largest market for solar installations in 2009 due to its attractive feed-in tariff. The PV industry generated $43 billion in global revenues in 2009, with Europe accounting for 5.60 GW, or 77% of world demand. The top three countries for solar use in Europe in 2009 were Germany, Italy and Czech Republic, which collectively accounted for 4.07 GW, with Italy the second largest market in the world. The third largest market in the world in 2009 was the United States, which grew 36% to 485 MW, followed by Japan, growing 109%.

If individual households can install PV systems, net metering and appropriate tariffs must be considered. Most electricity meters can accurately record in both directions, but regulations need to identify how excess production is treated. In 2002, Thailand was the first developing country to adopt net metering regulations (known as the Very Small Power Producer Program), providing streamlined interconnection arrangements for small renewable energy generators (under 1 MW in size, increased to 10 MW). In a net metering framework, excess production is when the output of the distributed generation exceeds the usage of the customer (customer’s generation is greater than usage), and the customer is a net exporter of electricity for that billing period. If there is

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excess production, the net metering rules should address how that production is treated. Excess production normally takes the form of a credit. Nonetheless, how the credits are calculated and treated varies widely (complications can arise in dealing with issues such as how to pay and refund value added taxes on electricity).

B. Hydropower

For many developing countries and transitional economies, renewable energy development means hydropower development\textsuperscript{32}. Hydropower produces about a sixth of the world's annual electrical output and over 90% of the electricity from renewable energy sources. It is the most used renewable energy resource, and the source with which investors and governments have the most knowledge and therefore comfort.

The potential barrier to grid connection is its input variability but storage potential must also be considered. Variations in input and demand mean that the ability to reserve and store energy is critical. Hydropower holds advantages over other forms of energy – conventional and renewable – for its storage abilities via use of reservoirs and pumped storage. Certainly most hydropower will suffer if there is a serious drought, though how much the drought affects immediate supply has to do with the type of facility, its engineering and storage capacity. An installation with a high (and reasonably sized) reservoir usually can maintain output over a dry period, whereas a reservoir or collection of water behind a run-of-river plant may not be able to operate during dry periods as easily. This means that most small hydropower plants offer less reliability in terms of supply, though some networks of small hydropower plants in different sites may be exposed to slightly different rainfall patterns. The need for long transmission lines can be one of the biggest encumbrances on power plant development. The transmission system in most countries has grown around initial need. Existing lines may not be in geographic locations conducive to additional power plant development, due to siting, geographic and resource limitations. Building new lines is costly and usually a time consuming process, and therefore not an attractive option for investors.

Large hydropower plants tend to require long transmission lines because few can be positioned near city centres. Proper Smart Grid design will compensate for voltage drops, line losses and other reliability issues.

C. Wind Energy

Wind offers a pollution-free means of generating electricity. Though used for electricity generation for about two centuries, wind power has become possible on a large scale only since about the 1980s, when technology advanced sufficiently to make large wind turbines cost-effective\textsuperscript{33}. As the technology improves, costs for wind power continue to decrease, making it an attractively cost-efficient source of renewable energy, at least with respect to onshore projects. Off-shore wind sites are also feasible and the number of installations is increasing, though they are less common and more costly. The difficulties with wind have to do with intermittency (winds vary in strength and intensity), appearance and noise levels.

\textsuperscript{32} Ibid.
\textsuperscript{33} Ibid.
Despite the problems of variability that accompany wind (if the wind stops, so do the turbines and electricity production), wind speeds are reasonably predictable. Estimates, when conducted diligently and regularly (one hour ahead is ideal), are generally accurate enough to provide sufficient information to allow for reliable forecasting and safe planning as long as less variable energy sources are used to balance the load or provide reserves. The key is to look at wind output along with other electricity output, to weigh the risks of the variability in relation to other electricity sources.

The amount of energy produced from a wind turbine depends on wind speed and the regularity of the energy produced depends on the length of time the wind blows at optimal or other speeds. This means that location is critical, and that wind speed and frequency must be assessed carefully prior to building.

From an investment perspective, wind is not quite cost competitive with conventional energy, but with constant advances in technology it is approaching competitiveness, even without subsidies. With the subsidies being offered currently in many countries, wind has become a prime investment, and once construction begins, wind farms are quick to build and the technology is reliable. Steps can be taken to assess the impact of reliability on the grid and to prevent emergencies that may result from reductions of wind power in systems that are heavily reliant on wind power.

D. Biomass

Biomass is energy derived from organic material (wastes, energy crops and natural plant life). It is carbon-based, absorbed from the atmosphere as carbon dioxide by plant life, using energy from the sun. Because plants may be then eaten by animals, animal waste can also be biomass material, but primary absorption is performed by plants, and biomass material can include garbage, wood, landfill gases and alcohol fuels produced through the fermentation of plants such as corn and sugar. It is the oldest source of renewable energy – used since the discovery of fire. Despite large technological advances in the last few decades, the most common use of biomass for energy is from firewood and crops. Considerable sustainability issues are associated with the use of biomass. For instance, some cooking stoves and other more rudimentary methods of using biomass for energy can be polluting, and use of crops may, in terms of life cycle, emit considerable carbon dioxide. Energy from biomass can be released directly in the form of heat, used to generate electricity, or converted to other usable forms of energy like methane, the main ingredient of natural gas, or transportation fuels like ethanol and biodiesel, the last of which can be produced from food waste products such as vegetable oils and animal fats. Biomass for energy is produced by the following methods: combustion system (boiler that produces steam); landfill gas (anaerobic decomposition of waste); gasification; and biogas from industrial waste streams.

Biomass has potential advantage of being adjusted to meet the demand. It does not have the intermittency problems of renewables such as solar and wind and it can be applied at a variety of different scales. It is an ideal RET to supplement power supply as embedded generation within the distribution system. Biomass has the potential to provide ancillary service like voltage regulation. Regulatory framework should adequately provide compensation to such services.

34 Ibid.
E. Geothermal Energy

Leading environmentalist Al Gore has said, “Geothermal energy is potentially the largest – and presently the most misunderstood – source of energy in the US and the world today.” The term “geothermal,” refers to the heat below the surface of the earth. Boreholes are drilled in order to access the heat source, where water or steam is pumped up and used to drive electric generators. Once used and cooled, the water is generally pumped back to the heat source. Because not all geothermal resources have water resources and some have only limited resources requiring water to be infused later, there are two wells, one injection well and one steam/hot water well. The geothermal resource is accessed with steam/hot water (or even another liquid), but geothermal doesn’t inherently mean that there is steam/hot water present.

Typically resources with temperatures greater than 150 degrees Celsius are used for electricity generation, with lower temperature/shallower resources applied to direct uses such as space heating. In at least 76 countries, there are 105 direct geothermal energy (ground source heat pumps) being used. Global geothermal power capacity surpassed 10 GW in 2008, led by the United States and the Philippines. Geothermal power facilities currently generate around 25% of the Philippines’ and Iceland’s total power production, plus they comprise a significant portion of the power production in multiple other countries.

Geothermal, like hydropower plants are site-specific and normally require lengthy transmission lines and very far from load centres since these plants are usually located beside a volcano and edges of the tectonic plate.

2.2.2. Grid Energy Storage

Grid energy storage refers to the methods used to store electricity on a large scale within an electrical power grid. Electrical energy is stored during times when production (from power plants) exceeds consumption and the stores are used at times when consumption exceeds production. In this way, electricity production need not be drastically scaled up and down to meet momentary consumption – instead, production is maintained at a more constant level. This has the advantage that fuel-based power plants (i.e. coal, oil, gas) can be more efficiently and easily operated at constant production levels. Energy storage in the grid may be achieved through mechanical or battery technologies.

2.2.3. Mechanical Technologies

A. Pumped Hydroelectric Storage (PHS)

Pumped hydroelectric storage uses a simple combination of water and gravity to capture off-peak power and release it at times of high demand. In practical terms, this is generally power generated during the night to meet peak load during the day as shown in Figure 21.

35 Ibid.
Pumped-hydro facilities typically take advantage of natural topography and are built around two reservoirs at different heights. Off-peak, inexpensive electricity is used to pump water from the lower to the higher reservoir, turning electrical energy into gravitational potential energy. The water is released back down to the lower reservoir when energy is more valuable, or perhaps when more electricity is needed, spinning a turbine which turns a generator to produce electric power.

Pumped hydro demonstrates the highest capacity for energy storage since its size is limited only by the size of the available upper reservoir. Practically, projects may be sized up to 4,000 megawatts—or even a few gigawatts—and operate at 70 to 85 percent efficiency, depending on design. The resulting energy typically costs between $600 and $1,000 per kilowatt-hour.

The first pumped hydro plant was built in Europe in the 1890s. Current plants have very long lives in the order of 50 years. Their fast response times enable them to participate equally well in voltage and frequency regulation, spinning reserve, and non-spinning reserves markets, as well as energy arbitrage and system capacity support.

Today, pumped hydro storage is a large, mature, and utility scale commercial technology that is in production at many locations around the world. In fact, it is the most widely used form of bulk-energy storage, accounting for more than 99 percent of such capacity worldwide. There are, however, limiting factors for pumped hydro storage. One such factor is site selection, as the technology requires a favorable local geology. It also requires a large initial investment and a fairly long construction period of up to seven or eight years. Finally, depending on the type of turbine installed at the dam, it can have a relatively slow reaction time to provide electricity.
B. Compressed Air Energy Storage (CAES)

Compressed air energy storage generally involves compressing air using inexpensive energy and using the compressed air to generate electricity when the energy is worth more. To convert the stored energy into electric energy, the compressed air is released into a combustion turbine generator system. As the air is released, it is heated and expands, and a spinning turbine turns a generator to produce electricity.

![Figure 22. Compressed Air Energy Storage in Underground Geologic Formations](https://share.sandia.gov/news/resources/releases/2008/images/compressor.gif)

For larger CAES plants, compressed air is stored in underground geologic formations, such as salt formations, aquifers, and depleted natural gas fields. This means that expansion of CAES is dependent on host rock availability at appropriate depths. Figure 22 depicts how energy storage can be stored during off-peak hours as compressed air in underground geologic formations to be released during peak demand hours. CAES is a technically mature approach to energy storage and the second most prevalent form of bulk-energy storage after pumped hydro. However, the feasibility and upfront cost are dependent on such geological factors as porosity, permeability, and the saturation of possible storage formations. Because the need for accessible geology sets practical limits on the technology, it will be necessary to analyse geologic potential before CAES can achieve wide market penetration. CAES also requires geo-mechanical modeling tools to develop safer, more efficient, and cost-effective underground storage systems.

CAES systems currently suffer from two primary limitations—inefficiency associated with the round-trip cooling and reheating process, and CO2 emissions produced by the reheating process. Air heats up when pressurised and cools down when expanded, so in all existing CAES systems, energy is lost as heat during compression and when air must be reheated before expansion. The energy required to reheat the air usually comes from direct combustion of natural gas, reducing efficiency, and increasing greenhouse gas emissions.
There are two commercial, first-generation CAES systems in operation—one in Huntorf, Germany and one in McIntosh, Alabama. Both demonstrate efficiency limitations. Apparently, the German plant is only 42% efficient and the Alabama plant is only slightly better. Second-generation CAES systems are being designed with the potential for lower installed costs, higher efficiency, and faster construction time than their first generation counterparts. In one design, a natural gas-fired combustion turbine generates heat during the expansion process, and two-thirds of the electricity generated is produced during the green compressed air cycle. New compressor designs and advanced turbo machinery are also leading to improved non-combustion, turbine-based CAES systems.

C. Flywheel Storage

Flywheel electric energy storage systems operate by storing kinetic energy in a spinning rotor / cylinder with a shaft in a robust enclosure as shown in Figure 23. A magnet levitates the cylinder, limiting friction-related losses and wear. The shaft is connected to a motor / generator. Electric energy is converted by the motor / generator to kinetic energy which is stored by maintaining the flywheel's rotational speed.

The stored kinetic energy is converted back to electric energy via the motor / generator, as the flywheel's rotational speed slows. When energy is extracted from the flywheel system, it is by the reduction in spinning/rotational speed based on the principle of conservation of energy.

![Figure 23. Flywheel Storage System](Source: Distributed Generation – Education Modules, Consortium on Energy Restructuring, Virginia Tech 2007)

Flywheels are commonly made of advanced high-strength materials and most systems use grid-sourced electricity to accelerate and decelerate the flywheel. They can have very fast response times—in the order of four milliseconds or less—be sized between 100 and 1,650 kilowatts, and used for short durations of up to one hour. They also have very high efficiencies of about 93% and lifetimes estimated at 20 years.
There are flywheel systems in development that directly use mechanical energy. These advanced systems have rotors made of high-strength carbon filaments suspended by magnetic bearings, spinning at speeds from 20,000 to more than 50,000 rpm in a vacuum enclosure. Such flywheels can come up to speed in a matter of minutes.

In general, flywheels have relatively modest capacities for energy storage. Research is underway to develop more advanced flywheel systems capable of storing larger quantities of energy, but these developments will not be available before 2014 or 2015 for anything approaching a large-scale demonstration.

They have power densities of five to 10 times that of batteries—meaning they require much less space to store a comparable amount of power—although there are significant practical limitations to the amount of energy they can store. Their comparatively small storage capacity would seem to limit flywheel applications to locally generated or distributed electricity sources. They are also shorter-duration systems that are not generally attractive for grid-scale support applications, which require many kilowatt or megawatt hours of energy storage.

Currently, flywheels may be best suited as surge-power devices that experience frequent charges and discharges of modest energy quantities at high-power rates. As such, they can complement battery storage devices. Manufacturers have shown flywheels to be a favourable form of energy storage due to their high efficiencies, long lifecycles, wide range of operating temperatures, and higher power and energy densities. Flywheel systems are also being positioned to provide ISO frequency regulation services, as they are both fast responding and efficient. They offer a number of other advantages, including their ability to reduce carbon dioxide emissions and avoid the cycling of large fossil power systems.

Material limitations currently constrain the speed at which flywheels can operate and their operational efficiency is limited, both in terms of leading-edge technology and overall system costs. However, because of the nature of their design, even incremental improvements will result in substantial extra energy storage and more attractive operational dynamics.

2.2.4. Electrochemical/Battery Technologies

Batteries typically deliver power for short periods and smooth out the peaks while different sources of power are switched on and off. They also demonstrate relatively high efficiency, up to 90%. Historically, they have not provided grid-scale performance, which requires storing and discharging energy at high rates or in very large quantities.

At present, the largest battery—larger than a football field—is located in Hebei Province, China and can store up to 36 megawatt-hours of electricity. The US$500 million facility is connected to 140 megawatts of wind and solar power-generation projects, as well as a Smart Grid transmission system.

Electrochemical batteries consist of two or more electrochemical cells. The cells use chemical reactions to create a flow of electrons or electric current. Primary elements of a cell include the container, two electrodes, and electrolyte material. The electrolyte is in contact with the electrodes, and current is created by an oxidation-reduction process involving chemical reactions between the cell’s electrolyte and electrodes.

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Some electrochemical batteries contain electrolytes in the same container as the cells where the chemical reactions occur. Other battery types called flow batteries use electrolytes that are stored in a separate container or tank outside of the battery cell container. In flow batteries, energy is stored as charged ions in two separate tanks of electrolytes, one each for positive and negative electrode reaction.

A key advantage to flow batteries is that the storage system’s discharge duration can be increased by adding more electrolytes and scaled with additional electrolyte tanks. It is also relatively easy to replace a flow battery’s electrolyte when it degrades. As a result, flow batteries have the potential for large-scale storage and are beginning to be used for storage that requires the averaging of generation from wind turbines.

Liquid metal batteries are another new battery type with the potential for large-scale storage. Made from inexpensive materials and with simple, easy-to-manufacture designs, they can respond in seconds and help with frequency regulation and smoothing out the intermittent supply of alternative energies.

There are an increasing number of chemistries being used for batteries. They include lead acid, nickel-cadmium (NiCad), lithium-ion (Li-ion), sodium/sulfur (Na/S), zinc/bromine (Zn/Br), vanadium-redox, and nickel-metal hydride (Ni-MH). Vanadium redox and zinc/bromide are two of the more familiar flow batteries.

A. Lead Acid Batteries

Lead acid (see Figure 24) is the most commercially mature rechargeable battery technology in the world, with major elements that have changed very little over 150 years. Given their mature technology, low capital cost and well-established manufacturing and distribution network, traditional lead acid batteries have wide application and are potentially attractive for large-scale energy storage.

Figure 24. Typical Lead Acid Architecture
(Source: http://www.alternative-energy-news.info/technology/battery-power/)
There have been few utility applications for lead acid batteries because of their relatively heavy weight, large bulk, cycle-life limitations, and perceived reliability and maintenance issues. In addition, there is very limited data available on the operation and maintenance costs of lead acid-based storage systems for grid support. A one-megawatt lead acid system operated for 12 years at a remote island location in Alaska, with very little visible degradation upon post-test analysis. Other lead acid energy systems have been deployed in sizes of 10 to 20 MW.

While advanced lead acid batteries based on a mature technology are attractive for large-scale energy storage because of their low cost, their limited cycle life presents a significant barrier to wide spread implementation. Adding select carbon materials to their design can apparently increase cycle life and capacity, however the underlying mechanisms are not all well understood. A better understanding of the fundamental physical, chemical, and electrochemical mechanisms behind both aspects of enhanced performance could lead to the design and fabrication of electrode structures with superior performance and reduced lifecycle cost.

**B. Lithium-ion Batteries**

Lithium-ion (Li-ion) batteries are relatively new as compared to lead acid batteries. Their high energy and power densities and relatively low weight have made them an attractive choice for applications with space constraints, such as mobile electronics.

They have also been considered for use in community level energy storage, transportable systems for grid support, commercial end-user energy management systems, home back-up energy management systems, frequency regulation, and wind and photovoltaic smoothing. In total, approximately 18 megawatts of grid connected advanced Li-ion battery systems have been deployed for demonstration and commercial service. The largest Li-ion battery storage project in the United States is located near Elkin, West Virginia with 32 MW of storage supporting a 98 MW wind-generation facility shown in Figure 25.

![Image of lithium-ion battery farm in West Virginia](http://www.forbes.com/sites/uciliawang/2011/10/27/worlds-largest-lithium-ion-battery-farm)

*Figure 25. World’s Largest Lithium-Ion Battery Farm in West Virginia, USA*
(Source: http://www.forbes.com/sites/uciliawang/2011/10/27/worlds-largest-lithium-ion-battery-farm)
Overall, Li-ion technologies have not yet demonstrated they can meet the performance and economic requirements for grid-scale applications, even with a high AC-to-AC efficiency of between 85 and 90 percent. They require advancements in materials, processing, design, and system integration to achieve broad market penetration.

C. Sodium-based Batteries

Sodium-based batteries store electricity in sodium- or sodium compounds-based electrodes (see Figure 26). They have attractive attributes for large-scale energy storage, including the fact that sodium is inexpensive and readily available. At least one manufacturer announced plans to produce novel sodium-based batteries with a production cost under US$300 per kilowatt-hour, and eventually, under US$200 per kilowatt-hour—which is less than lithium-ion, but still more expensive than lead acid batteries. Sodium-sulfur batteries—with an installed system capacity of over 300 MW globally—comprise one of the more mature and commercially viable technologies for large-scale electrical energy storage. They are used in utility distribution grid support, wind power integration, and high-value service applications on islands. Sodium-sulfur batteries can be cost-effective to implement on a large scale and have been used for grid storage in Japan and the USA.

These batteries offer a quick, sub-second response and can store multi-megawatts of electricity in a modular system. The round-trip AC-to-AC efficiency of these systems is approximately 80%. For both power and energy applications, the battery’s power/energy ratio can be adjusted via its cell and stack designs. The estimated life is approximately 15 years after 4,500 cycles at 90% depth of discharge.

Figure 26. Cut-away Schematic Diagram of a Sodium-Sulfur Battery.
(Source: NASA John Glenn Research Centre)
D. Vanadium Redox Batteries

Vanadium redox batteries are the most mature of all flow battery systems currently available. Like other flow batteries, their power capacity and energy storage vary depending on the size of the electrolyte tanks. They can be designed to provide energy for as little as two hours to more than eight hours, depending on the application.

Vanadium redox batteries are unique in that they use one common electrolyte, which provides potential opportunities for increased cycle life as shown in Figure 27. To provide needed electricity, the electrolyte flows to a redox cell with electrodes, generating current. As with conventional batteries, the electrochemical reaction can be reversed, allowing the system to be repeatedly discharged and recharged. The lifespan of flow-type batteries is not strongly affected by cycling.

Vanadium redox system manufacturers estimate the lifespan of the cell stacks at 15 years or more, and the balance of plant and electrolyte at 25 years. They also claim to achieve a cycling capability of 10,000 or more cycles at 100 percent depth of discharge. The physical scale of vanadium redox systems tends to be large, due to the large volumes of electrolyte required for utility scale projects.

E. Zinc-bromine Batteries

Zinc-bromine (Zn / Br) is a redox flow battery that uses zinc and bromine in solution to store energy as charged ions in electrolyte tanks (see Figure 28). Less developmentally mature than vanadium redox systems these batteries are in an early stage of field deployment and demonstration.
Manufacturers claim estimated lifetimes of 20 years, long cycle lives, and operational AC-to-AC efficiencies of 65 to 70 percent. Module sizes differ by manufacturer, but can range from five to 500 kilowatts, with variable storage duration from two to six hours depending on the application and need.

F. Liquid Metal Batteries

Liquid metal batteries generally consist of molten-metal electrodes and a molten salt electrolyte. One such battery developed at the Massachusetts Institute of Technology includes three distinct layers—a negative electrode made of magnesium, a positive electrode made of antimony, and a molten salt electrolyte.

This battery technology has potential for stationary energy storage applications as a result of its low-cost materials, ability to quickly absorb large amounts of electricity, and self-segregating components.

![Zinc-Bromine Battery Diagram](http://energystoragedemo.epri.com/cec/zbb/tech_desc.asp)

**Figure 28. Zinc-Bromine Battery**

(Source: http://energystoragedemo.epri.com/cec/zbb/tech_desc.asp)

2.2.5. Other Energy Storage Technologies

In addition to mechanical and electrochemical technologies, there are other approaches that show promise for energy storage. They include hydrogen, thermal, superconducting magnetic energy, and capacitors, each of which is discussed briefly hereafter.
A. Hydrogen

Over the years, there have been many attempts to use hydrogen as an electrical energy storage medium. Typically, after the hydrogen is produced, it is compressed or liquefied, stored, and then converted back to electrical energy or heat.

Hydrogen energy storage is potentially well suited for renewable integration, and particularly for large-scale wind and solar integration as shown in Figure 29. It also has the potential to be scalable. In future, underground storage may be able to store hydrogen in large quantities and at a competitive cost.

![Figure 29. Hydrogen Energy Storage](http://www.oilempire.us/hydrogen.html)

The primary advantage of hydrogen technology is that it is a high-energy density fuel when compared to pumped hydro storage and batteries. Its main drawback is the high number of energy conversions required. Hydrogen’s potential for grid-scale applications is severely limited by an AC-to-AC efficiency in the range of 20-25%. Effectively, this means that the sales price of the hydrogen would have to be at least four times the purchase price in the same market.
B. Superconducting Magnetic Energy

Superconducting magnetic energy storage systems (see Figure 30) use coils made of superconducting material as their storage medium. Other system components include power conditioning equipment and a cryogenically cooled refrigeration system. The coil is cooled to a temperature below that necessary for super conductivity, and energy is stored in the magnetic field created by the flow of direct current in the coil. Once the energy is stored, the current will not degrade, so the energy can be stored indefinitely—as long as the refrigeration is operational.

![Image of a superconducting magnetic energy storage system](http://www.physics.oregonstate.edu/~demareed/313Wiki/doku.php?id=superconductor_electricity_transmission)

*Figure 30. The World Largest Superconducting Magnetic Energy*

(Source: http://www.physics.oregonstate.edu/~demareed/313Wiki/doku.php?id=superconductor_electricity_transmission)
C. Capacitors

Capacitors store electric energy as an electrostatic charge (see Figure 31). A number of new, larger-capacity capacitors appear to be well-suited for energy storage. Relative to conventional capacitors, they can store significantly more electric energy. They can also deliver a significant amount of energy over a short period of time, making them attractive for high-power applications that require short or very short discharge durations.

![Figure 31. Electric Flux Capacitor for Grid Storage Application](http://techzoho.blogspot.com/2012/07/cleantech-news-from-cleantechnica_17.html)

A research team from Drexel University applied new nanotechnology to develop an “electrochemical flow capacitor” (EFC) that it says can cost-effectively store grid-level quantities of electrical energy, and charge and discharge quickly, making it suitable to manage intermittent flows from renewable energy sources. In Figure 31, EFC is composed of electrochemical cells connected to two external electrolyte reservoirs and nanoscale carbon particles are used as energy carriers. A slurry of uncharged carbon particles suspended in electrolyte tanks are pumped through a flow cell, where they pick up and carry electrical charge. They then flow into storage reservoirs for use as needed.
2.3. SMART TRANSMISSION GRID APPLICATIONS

The availability of synchronised phasor measurements has given rise to the possibility of two categories of new and improved applications. One category has been broadly referred to as Wide-Area Control. It is in the same family as all existing automatic control and protection, which are mostly local, that is, the actuating signal source and the control signal destination are in the same substation.

Synchronised measurements and fast communication now make it possible for such control to be wide-area or regional. Special and unique examples of such wide-area control already exist and are called Special Protection Schemes (SPS). The increasing availability of phasor measurements will make the development of more wide-area controls easier. Some example possibilities are provided below.

The other category is the enhanced control centre functions. The main functions of the control centre – SCADA, State Estimator, Contingency Analysis, etc. – are for the system operator to monitor the power system and make operational changes, either using supervisory control or by telephone, to ensure the reliable and efficient operation of the system. The availability of phasor measurements at faster rates can improve these functions. For example, a faster and more accurate state estimator can both be a replacement for SCADA data and be able to provide better input to contingency analysis and other downstream EMS functions. Such a State Estimator is described below.

2.3.1. Wide-Area Control

The proposed control concepts described here are all wide-area controls. Although local controls continue to be improved using newer technologies, the conceptual functionality of these local controls will remain the same. The wide-area controls presented here will often take care of the local controllers but the main objective is to improve the overall stability of the power system. The concepts are presented in the order of increasing complexity, also implying that the ones presented first would be easier to implement.

2.3.2. Frequency Control

Frequency is controlled by balancing load with generation. The primary governor control at the generators is local while the secondary automatic generation control (AGC) that adjusts the governor set points is wide-area. The primary control is continuous whereas the secondary control is discrete usually using 2-4 second sampling. Given that all generators in a region are no longer owned by the same organisation, this wide-area AGC has become more decentralised. Ancillary markets for regulation capacity have developed to handle this service. The Federal Energy Regulatory Commission (FERC) ancillary service regulations do allow third-party AGC but a new communication-computation-control scheme needs to be developed before this can occur in any large scale. As this control is quite slow (2-4 second sampling), feasibility of control is not a problem. The more complex communication scheme required is also not a problem; although a meshed communication network is required rather than the present star network, the bandwidth requirement remains modest. However, such a network introduces other modes of failures like signal delays and the controls have to be robust enough to handle them.

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38 Smart Transmission Grid Applications, Consortium for Electric Reliability Technology Solutions and was funded by the U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, Transmission Reliability Program.
2.3.3. Regional Voltage Control

Voltage control in North America has always been local, although Europe and China are trying some regional control schemes. FERC recognises voltage-Voltage Ampere Reactive (VAR) control as an ancillary service but it has been difficult to develop any auction markets for this service.

Control schemes for regional voltage control would be useful in North America as voltage collapse has played a prominent part in all recent blackouts. This type of control, like frequency control, is relatively slow and so the feasibility of the control and communication is not an issue. The main hurdle has been the selection of input and output variables of the controller that can handle all the varied operating conditions that the power system endures. Thus this challenge is a classical one of developing a practical robust controller.

2.3.4. Small Signal Stability Control

Small signal instability occurs when a system perturbation, even a small one, excites a natural oscillatory mode of the power system. These oscillations are slow, usually under 1Hz. The main method used today to guard against small signal instability is the off-line tuning of power system stabilisers (PSS). These PSS are local controllers on the generators. Thus local controllers are used to mitigate system oscillation modes, a procedure that works well for local oscillation modes but not inter-area modes. Phasor measurements have already been shown to be very helpful in tracking the oscillation modes and their damping in near real time. New controllers need to be developed that can use system-wide inputs (not necessarily more inputs per controller but input signals from further away). Such remote signal inputs will obviously require a more flexible communication mesh network.

Another control concept is to adaptively change the PSS set points according to the power system operating conditions. This would be analogous to the AGC control by introducing a secondary control scheme that would periodically adjust the set points of the local PSS controllers as the system changes. The challenge here is that the calculation of PSS set points requires large analytical calculations, which are today done off-line but will have to be done on-line in this case. The speed of calculation is not a major concern as changing the set points can be done quite infrequently, probably minutes.

2.3.5. Voltage Stability Control

Voltage instability occurs when a change in the power system causes an operating condition that is deficient in reactive power support. Guarding against such instability requires the anticipation of such contingencies that can cause voltage instability and taking preventive action. New preventive control schemes are needed that can also include special protection schemes that could isolate those areas with VAR deficiencies.

This is not a stability control in the traditional sense that responds to a disturbance. This is an action plan to ensure that the system operating condition does not stray into an area where a perturbation can cause voltage instability. This calculation requires good contingency analysis, which in turn requires a good real time model (state estimator).
2.3.6. Transient Stability Control

The development of such a control scheme is by far the most difficult because a disturbance that can cause instability can only be controlled if a significant amount of computation (analysis) and communication can be accomplished very rapidly. This concept is approached in three increasingly difficult levels:

- First, is to use off-line studies to manually adjust protective schemes which would operate only if the disturbance occurs;
- Second is to automatically adjust these protective schemes with on-line calculations; and
- Third and final would be to directly operate the control actions after the disturbance occurs.

2.3.7. “Soft-Wired” Special Protection Schemes

A step advance in this direction will be to generalise special protection schemes (SPS) to control transient stability. These SPS today are developed from the results of voluminous off-line studies and are implemented with a ‘hard-wired’ communication system. Thus, the system values and statuses monitored and the breakers controlled cannot be modified. What is proposed here is the development of a generalised communication system that can enable the implementation of new SPS by software modification. Although many phasor measurements and a comprehensive communication scheme will be required in this type of control, the computation requirements will be modest as the control schemes are largely defined off-line.

2.3.8. On-line Setting of SPS

A step forward will be to develop methods to control transient stability but with less dependence on off-line studies and more use of on-line computation. The main idea here is to use more real-time data to determine what control is needed. What is proposed here is the development of soft-computing techniques using pattern-recognition, neural networks, expert systems, etc. to process the real-time data to decide the best control action. Of course, much off-line training of the software may still be required off-line but the expectation is that the control action would be much more efficient than those purely decided off-line.

2.3.9. Real Time Control of Transient Stability

The objective here is to develop a global control for transient stability (with no off-line assists). For this to be feasible, the computation needed to determine the disturbance scenario and then computing the necessary controls for stabilisation, has to be in the same time-frame as today’s protection schemes (milliseconds). Whether this is indeed possible with today’s technology is not known. However, the goal here would be to determine what kind of communication-computation structure will be needed to make this feasible.
2.3.10. Real Time Modeling (State Estimation)

The state estimator (SE) today runs at the control centre EMS using the data from the SCADA real time data and the static database. There are two levels of SEs running today– at the Balancing Authorities (BA) level and at the Reliability Coordinators (RC) level. The BA SCADA gets the real time data from the RTUs and uses that for its SE; it also passes on the same real time data to the ISO level for its SE.

2.4. DISTRIBUTION AUTOMATION

Legacy or traditional substation automation protocols and architectures typically provided basic functionality for power system automation and were designed to accommodate the technical limitations of the Information and Communications Technology (ICT) available for implementation. There has recently been a vast improvement in ICT that has changed dramatically what is now feasible for power system automation in the substation. Technologies such as switched Ethernet, TCP/IP, high-speed wide area networks, and high-performance low-cost computers are providing capabilities that could barely be imagined when most legacy substation automation protocols were designed.

2.4.1. Substation Automation (SA) and IEC 61850

Substation Automation (SA) is quite a mature application, which has been performed for many years. Its core functions include protection, local control and supervision, remote control and supervision, equipment supervision, metering, measuring and online diagnosis.

The possibility to build Substation Automations Systems (SAS) rests on the strong technological development of large-scale integrated circuits, leading to the present availability of advanced, fast, and powerful microprocessors (see Figure 32). The result has been an evolution of substation secondary equipment, from electro-mechanical devices to digital devices. This in turn has provided the possibility of implementing SA using several intelligent electronic devices (IEDs) to perform the required functions (i.e. protection, local and remote monitoring and control).
The integration of substation automation functions into the Smart Grid architecture is accelerating its implementation to new distribution substations. Substation automation equipment, including communications, protective relays, SCADA devices, and related sensors is now a significant and mature market and IEC 61850 is the enabling factor in the speedy transformation of substation automation design.

IEC 61850 is a set of standards for the design of electrical substation automation and covers electrical engineering and power quality requirements, platforms or communication protocols, management of systems and projects, definition of data and service models and many more. It is now the established global standard for specification requirement of substation automation.

In 1995, the International Electrotechnical Commission (IEC) began developing IEC 61850, Communication Networks and Systems in Substations, which defines a standard protocol for substation control and protection, including alternate communications stacks to be used with a standard substation-defined object-oriented user layer. The objectives set for the standard were:

- A single protocol for complete substation considering modeling of different data required for substation;
- Definition of basic services required to transfer data so that the entire mapping to communication protocol can be made future proof;
- Promotion of high interoperability between systems from different vendors;
- A common method/format for storing complete data;
- Define complete testing required for the equipment which conforms to the standard.

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39 IEC Smart Grid Standardisation Roadmap, by Standardisation Management Board (SMB) Smart Grid Strategic Group (SG3) June 2010; Edition 1.0, Page 58, Figure 10
The ten existing parts of IEC 61850 have been issued as international standards, although future revisions are likely as field installations reveal issues and shortcomings. Some important issues on substation integration and automation are discussed hereafter.

A. Development of Protocols

There are various protocol choices depending on the protocol application area of the system. Different application areas are in different stages of protocol development and industry efforts. The status of development efforts for different applications will help determine realistic plans and schedules for specific projects.

A communication protocol allows communication between two devices. The devices must have the same protocol (and version) implemented. In the area of traditional SCADA communication protocols, the Data Acquisition, Processing and Control Systems Subcommittee of the IEEE PES Substations Committee began developing a recommended practice in the early 1980s in an attempt to standardise master/remote communications practices. At that time, each SCADA system supplier had developed a proprietary protocol based on technology of the time. These proprietary protocols exhibited varied message structures, terminal to Data Circuit-terminating Equipment (DCE) and DCE-to-channel interfaces, plus error detection and recovery schemes, thus posing a challenge in the integration of communication functions in a Smart Grid.

B. Limits to Higher IED Functionality

The need for a standard IED protocol dates back to the late 1980s. IED suppliers acknowledge that their expertise is in the IED itself – not in two-way communications capability, the communications protocol, or added IED functionality from a remote user. Though the industry made some effort to add communications capability to the IEDs, each IED supplier was concerned that any increased functionality would compromise performance and drive the IED cost so high that no utility would buy it. Therefore, the industry vowed to keep costs competitive and performance high as standardisation was incorporated into the IED.

C. Communications Interfaces

There are interfaces to substation IEDs to acquire data, determine the operating status of each IED, support all communication protocols used by the IEDs, and support standard protocols being developed. There may be an interface to the energy management system (EMS) that allows system operators to monitor and control each substation and the EMS to receive data from the substation integration and automation system at different periodicities. There may be an interface to the distribution management system with the same capabilities as the EMS interface.

D. Utility Communication Architecture

The use of international protocol standards is now recognised throughout the electric utility industry as a key to successful integration of the various parts of the electric utility enterprise. One area addresses substation integration and automation protocol standardisation efforts. It is crucial to have in place a robust utility communication architecture that can capably respond to the development and deployment of a Smart Grid.
Take for example the two capabilities a utility considers for an IED. The primary capability of an IED is its standalone capabilities, such as protecting the power system for a relay IED. The secondary capability of an IED is its integration capabilities, such as its physical interface (e.g., RS-232, RS-485, Ethernet) and its communication protocol (e.g., DNP3, Modbus, IEC 61850 MMS). This is where IEC 61850 standard protocol for substation control and protection and communication plays a crucial part for the deployment of Smart Grids.

E. Standardised Protocols and IEC 61850

Since its publication in 2004, the IEC 61850 communication standard has gained more and more relevance in the field of substation automation. It provides an effective response to the needs of the open, deregulated energy market, which requires both reliable networks and extremely flexible technology – flexible enough to adapt to the substation challenges of the next twenty years. IEC 61850 has not only taken over the drive of the communication technology of the office networking sector, but it has also adopted the best possible protocols and configurations for high functionality and reliable data transmission. Industrial Ethernet, which has been hardened for substation purposes providing a speed of 100 Mbit/s, offers enough bandwidth to ensure reliable information exchange between IEDs as well as reliable communication from an IED to a substation controller.

The definition of an effective process bus offers a standardized way to digitally connect conventional as well as intelligent current transformers (CTs) and voltage transformers (VTs) to relays. More than just a protocol, IEC 61850 also provides benefits in the areas of engineering and maintenance, especially with respect to combining devices from different vendors.

2.4.2. Distribution Feeder Automation (Feeder Remote Terminal Unit)

When advanced metering infrastructure (AMI) and smart meter deployments begin, the next major focus area for Smart Grid projects is Distribution Automation (DA) and Management System (DMS). In particular, the automated isolation and restoration of distribution feeder faults is one application that can have significant impact on improving system reliability and quality of service. The value of new intelligent power meters and home area networks is largely dependent on a reliable and efficient distribution system that delivers quality power to the consumer.

Fault management plays a greater role in the operation of distribution systems. It is imperative to localise faults in the distribution network (feeders) as precisely as possible in order to restore power as quickly as possible to those sections of the network which have been de-energised although they are not faulty. For this purpose, there are applications and equipment designed for distribution system operation which narrows down the fault location as small as possible by analysing the fault messages and proposes ways of isolating the operational equipment which is suspected of being faulty. After that equipment has been isolated, switching proposals are then formulated whereby voltage can be restored to the fault-free but de-energised sections of the system without causing overload situations. Installing Feeder Remote Terminal Units (RTUs) at strategic locations along the distribution network enables the process just described.

An RTU (sometimes referred to as a remote telemetry unit or remote terminal unit) is a stand-alone data acquisition and control unit, generally microprocessor based, that monitors and controls equipment at a remote location. Its primary task is to control and acquire data from process equipment at the remote location and to transfer this data back to a central station. It generally also has the facility for having its configuration and control programs dynamically downloaded from some central station. Although, traditionally, the RTU communicates back to some central
station, it is also possible to communicate on a peer-to-peer basis with other RTUs. The RTU can also act as a relay station (sometimes referred to as a store and forward station) to another RTU that may not be accessible from the central station.\footnote{Gordon R. Clarke, Deon Reynders, Edwin Wright, Practical modern SCADA protocols: DNP3, 60870.5 and related systems Newnes, 2004 ISBN 0-7506-5799-5 pages 19-21}

An RTU monitors the field digital and analog parameters and transmits data to the Central Monitoring Station. An RTU can be interfaced with the Central Station with different communication media (usually serial (RS232, RS485, RS422) or Ethernet). RTU can support standard protocols (Modbus, IEC 60870-5-101/103/104, DNP3, IEC 60870-6-ICCP, IEC 61850 etc.) to interface any third party software.\footnote{Remote Terminal Unit, Wikipedia}

Modern RTUs are usually capable of executing simple programs autonomously without involving the host computers of the Distribution Control System (DCS) or SCADA system to simplify deployment, and to provide redundancy for safety reasons. The flexible and modular designed RTUs provide a complete solution with many integrated functions. The scalability of the system allows perfect adaptation for station reinforcement, retrofit and upgrades. The open architecture of the RTU supports adaptation to different applications. Future functional and quantitative extensions are easy to realise at any time through hardware or software upgrade for various applications on Distribution and Feeder Automation.

"Self-healing" feeder networks are typically implemented using two approaches - scripted (rules-based) and model driven. The model-driven approach is often referred to by various acronyms, including FDIR (Fault Detection, Isolation and Restoration) and FLISR (Fault Location, Isolation and Service Restoration). This automated detection of feeder faults and reconfiguration to restore power to un-faulted sections is a DA application that has been around for many years. It can be argued that FDIR is a true Smart Grid application that was somewhat ahead of its time.

Since the late 1990s, utility performance regulations (reward/penalty structures) and increasing penetration of distributed energy resources and microgrids have increased pressure on utilities to respond efficiently to distribution faults and quickly restore power to as many customers as possible. The automated fault handling performed by FDIR provides many benefits to the utility and the customer that are well chronicled. These benefits include:

- Shorter outage durations
- Fewer sustained outages
- Improved performance indices
- Enhanced operational efficiencies
- Improved service quality
- All restoration technologies share the same core objectives; that is, to:
  - Accurately detect and locate feeder faults
  - Isolate the faulted portion(s) of the feeder
  - Restore power as quickly as possible (upstream and/or downstream of the faulted section).

FDIR is traditionally deployed as an advanced system-level application running on the DMS in the control centre. In recent years, some other methods of applying feeder restoration technology have entered the marketplace. There are still essentially two basic types of self-healing feeder architectures in use – distributed and centralised. The distributed approach moves the automation
intelligence out into the devices located along the feeders using scripted logic and peer-to-peer communication, while the centralised approach utilises a control-centre based algorithm and requires direct communication between the control centre and the devices in the field.

Some Smart Grid issues on feeder RTUs are identified and discussed hereafter.

A. On Distributed Approach

With the distributed approach, controller devices at the switch/breaker location contain the automation logic needed to restore a selected portion of the network. These devices communicate among themselves in a peer-to-peer fashion to determine where the fault has occurred and to determine the appropriate switching actions necessary for restoration.

Since the intelligence needed for restoration is localised and distributed among the controllers, this approach uses preprogrammed, or scripted, solutions based on a known baseline topology for that section of the network. Since no real-time network model is utilised, the system can have difficulty handling multiple faults and must usually be deactivated if the network is in an abnormal state (e.g., if any temporary switching has been performed.

The controllers in a distributed system are generally vendor specific and often must interface with another automated control or feeder RTU at the switch, or may double as the switch control themselves. In either case, basic controller requirements for FDIR include the ability to detect feeder fault currents, detect voltage loss upstream of the switch, and store historical load data at the switch, which is then used to make downstream restoration switching decisions.

The advantages of the decentralised approach includes faster performance, quicker deployment, and suitable for small “islands” of automation. However, its disadvantages are it requires more field maintenance/programming and specialised equipment. The lack of real-time network model also limits flexibility and unnecessary switch operations are performed by opening up all switches before isolating the fault.

B. On Centralised Approach

The centralised architecture is a model-driven solution and typically involves running FDIR as a subsystem of the DMS at the control centre. Since the restoration intelligence is resident within the DMS, no specialised controllers are required at the substation or switch. This allows the utility to leverage automated controls that may already be in place. If these switch or recloser controls are capable of fault current detection, then no additional hardware may be required at all. If the fault detection capability is not provided by the switch control, then there are a number of low-cost RTU options available that can provide the needed telemetry.

Unlike the pre-programmed logic used in the distributed scheme, centralised FDIR utilises a real-time load flow model of the network, meaning restoration actions can take place even if abnormal network conditions exist. It handles multiple fault scenarios effectively. It makes possible more complex switching scenarios and load-transfer decisions such as a secondary load transfer to create additional capacity on the alternate feeder.

Using the model and the telemetered data, the FDIR application develops a switching sequence to restore as many de–energised feeder sections as possible using a minimum number of switching actions within the allowed overload and voltage drop limits of the impacted feeders and power sources. Another advantage of the centralised scheme is that FDIR can be configured to
operate in a semi-automatic or automatic mode. In semi-automatic mode, the application creates the necessary restoration switching plan, but does not perform the actions until approved by the operator.

The advantage of the centralised approach is all data is available at the control centre and it can effectively handle abnormal network conditions because it is a model-based solution. It does not require any specialised field equipment nor re-programming for expansion. This can increase the return on investment (ROI) through other feeder optimisation applications (e.g. Integrated Volt/VAR Control). Larger implementations of the centralised approach however, can be costlier. It also requires controller communication directly with the control centre and an accurate network load model before implementation.

While the two general schemes, distributed or centralised, may remain the first order of choice for implementing feeder automation, there are evolutions of each of these basic architectures that can provide utilities with a combination of the advantages provided by both. A “semi-distributed” system is a model-driven scheme in which the FDIR algorithm is hosted at the substation level instead of at the control centre. In this configuration, an intelligent substation controller serves as the field “host” for FDIR, utilising a local network connectivity model updated with real-time topology for the area of automation. All feeder devices that are part of the automation scheme communicate back to the substation level only, and specialised field hardware is not required.

The FDIR controller at the substation (see Figure 33) can also act as a data concentrator, communicating back to a primary SCADA or DMS system for enhanced system visualisation at the control centre level. Expansion to multiple substations and feeders within the automation “island” is accomplished through the appropriate updates to the network model. The model can be updated offline when network updates or additions are made, and then downloaded to the controller remotely or loaded locally at the substation.

![Figure 33. In A Semi-Distributed Approach, An FDIR Model is Resident at One Substation Within the “Island.”](http://www.electricenergyonline.com/?page=show_article&mag=&article=554)
As an alternative to the traditional centralised architecture, utilities can also choose a separate centralised system that provides the benefits of the model-based approach to FDIR without the up-front cost and resources typically required to develop the network model. New ways to configure systems can simplify the process of creating this network model by using pre-defined network templates to create automation “islands” (see Figure 34).

The system provides the user a matrix of templates for differing numbers of substations, feeders and switches, allowing the utility to select the one that matches a particular island. A simple menu-based tool then helps define the specifics for each device in the chosen template (i.e. switch control, communications parameters, etc.).

Using this approach, an automation island can be configured and operational in less time than it takes to program and implement a rules-based peer-to-peer system, at a comparable cost. This standalone type of centralised system links easily to a SCADA or DMS. It can expand to include other model-driven applications such as Loss Minimisation and Integrated Volt/Var Control (IVVC), providing further justification to the utility for the investment in an automation system.

Figure 34. A New Centralised System Can Use Pre-Defined “Island” Templates to Build a Network Model for FDIR Quickly
(Source: http://www.electricenergyonline.com/?page=show_article&mag=&article=554)

The wave of architecture options and technology choices has not yet peaked and continues to develop. It continues to evolve as utilities today pursue the most effective feeder restoration solution to support their distribution automation systems. DA looks to be a Smart Grid trend that will see increased utility investment in the coming years. In an era in which demonstrable efficiency and customer satisfaction are increasingly important, FDIR is poised to play a vital role as a technology that delivers clear improvements in both centralised and distributed approach. In fact it can be concluded that FDIR is one of the key drivers of Smart Grid future technology.
The two traditional approaches to self-healing feeders have distinct pros and cons that must be carefully weighed when making planning and investment decisions. Yet with the newest innovations in model-driven FDIR system architectures, utilities are no longer limited to choosing between the two. New combined approaches are bringing important advantages over either approach alone, depending on the unique aspects of each deployment. If each approach has formerly forced utilities to choose which wave to ride, the new technology is like two waves converging, offering users a powerful combination of tools to reach their goals. In fact, the future of FDIR may be an empowered utility in which users are likely to find that a mix of these architectures and systems allow them to define a hybrid approach that provides them with the best performance and value.

The PEA has already limited deployment of FDIR in its distribution system as shown in Figure 35. Regardless of the approach, both PEA and its customers will greatly benefit from the FDIR. The important matter will be the number of Feeder RTU that will be deployed in the Pattaya City Smart Grid pilot area. The approach should be on a case to case basis where PEA planning simulation and modeling will recommend the best approach that will provide more reliability and flexibility in the distribution system in order to achieve the greatest benefit at the least cost.

Figure 35. PEA Feeder RTU with SCADA / DMS
(Source: PEA’s Effective use of information technology through its SCADA/DMS)
2.5. CUSTOMER HOME AUTOMATION AND DEMAND RESPONSE

In a Smart Grid, smart meters at the customer level communicate consumption data to both the user and the service provider. Smart meters communicate with in-home displays to make consumers more aware of their energy usage. Going further, electric pricing information supplied by the service provider enables load control devices like smart thermostats to modulate electric demand, based on pre-established consumer price preferences. More advanced customers deploy Distributed Energy Resources (DER) based on these economic signals. And consumer portals process the Advanced Metering Infrastructure (AMI) data in ways that enable more intelligent energy consumption decisions, even providing interactive services like prepayment.

2.5.1. Advanced Metering Infrastructure

Deploying an AMI is a fundamental early step to grid modernisation. AMI provides the framework for meeting one of the Smart Grid’s principal characteristics – consumer participation or Demand Response (DR). AMI is not a single technology implementation, but rather a fully configured infrastructure that must be integrated into existing and new utility processes and applications. Three features comprise the AMI system: “smart” meters, a two-way communications network and the information technology systems to support their interaction. AMI uses internal communications systems to convey real-time energy use and load information to both the utility and to the customer as shown in Figure 36.

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Figure 36. AMI Showing the Smart Meter in Constant Communication with Utility and Customer
(Source: Electric Power Research Institute)

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43 Advanced Metering Infrastructure, Conducted by the National Energy Technology Laboratory for the U.S. Department of Energy Office of Electricity Delivery and Energy Reliability, February 2008
This infrastructure includes home network systems, including communicating thermostats and other in-home controls, smart meters, communication networks from the meters to local data concentrators, back-haul communications networks to corporate data centres, meter data management systems (MDMS) and, finally, data integration into existing and new software application platforms. Additionally, AMI provides a very "intelligent" step toward modernising the entire power system. Figure 37 graphically describes the AMI technologies and how they interface.

The service provider (utility) employs existing, enhanced or new back office systems that collect and analyse AMI data to help optimise operations, economics and consumer service. AMI can provide immediate feedback on consumer outages and power quality, enabling the service provider to rapidly address grid deficiencies. And AMI’s bidirectional communications infrastructure also supports grid automation at the substation (SA/DA/DMS) and feeder circuit level (DMS/OMS/FDIR). The vast amount of new data flowing from AMI allows improved management of utility assets as well as better planning of asset maintenance (AAM), additions and replacements. The resulting more efficient and reliable grid is one of AMI’s many benefits.

AMI’s smart meters and communications capabilities, combined with special rate plans, allow customers to better understand their energy consumption and, by responding to various pricing signals, to potentially reduce their electricity bills. AMI provides the capability to monitor equipment and can quickly convey information about certain malfunctions and operating conditions. It also facilitates customers’ ability to achieve the full array of benefits that can be realised by certain customer-owned advanced technologies and appliances.
Of special interest is the Smart Meter, which is the heart of AMI, since this will be the focus of PEA's massive deployment in their Smart Grid Pilot Project in Pattaya City. Smart meters are solid state programmable devices that perform many functions. Local and global standard features and functionalities are being employed, which incorporate most if not all of the following properties.

A. Smart Meter Standard Features and Functionalities

(1) Time-based pricing (TBP)

A smart meter is capable of recording consumption that incorporates Time of Day (TOD) and Time of Use (TOU) pricing mechanism to provide options for the consumer to limit use of power during peak period (high price) and maximise use during off-peak (low price). More advanced features in more advanced electricity market structure will include critical peak pricing (CPP), real-time pricing (RTP) also called dynamic pricing and peak load reduction credits (PLRC). Combined with a well-designed tariff scheme, this feature enables DR that will reduce peak load considerably.

(2) Consumption data storage for consumer and utility

It can record both Active (Watt-hour) and Reactive (VAR-hour) energy. This enables regulators to implement power factor incentive schemes and encourage users to implement a power factor improvement program that improves overall system efficiency and reduces electricity cost. It can transmit or communicate information of the load and energy consumed in minutes (or seconds) to both the utility and consumer. This feature enables and enhances time-based pricing (TBP). It automatically resumes operational functionality after loss of power and retains all information held in its data storage prior to such power failure. This feature maintains data integrity and accuracy.

(3) Net metering

It is capable of recording exported and imported power (bi-directional flow) of consumers with embedded generator or integrated renewable energy supply like solar panels. Combined with other features, this transforms the passive consumer into an active “prosumer”. Aggregated prosumers can evolve into a virtual power plant by selling their self-generated power.

(4) Loss of power (and restoration) notification

It can detect, record and transmit loss and restoration of power notice to both utility and consumer. This feature enables Outage Management System (OMS) and improves system reliability through real-time outage information. OMS reduces the impact of outages by reducing the time and resources used to deal with them, through automated call-taking, prediction and the integration of AMI integration and Integrated Voice Response (IVR). In simpler terms, it predicts the location of a failed fuse or breaker, prioritises restoration efforts, provides information on the extent of outages, calculates restoration times and manages repair crews. Some experts believe that the US could have recovered from Hurricane Sandy much better had they invested in this smart grid upgrade.

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44 Smart Metering Implementation Programme / Smart Metering Technical Equipment prepared by Department of Energy and Climate Change. Draft provided to Parliament’s libraries dated September 2012, UK
(5) Remote turn-on / turn-off operations (Load Switch)

A smart meter can be remotely turned on and turned off. This feature enables, among others, demand response mechanisms on voluntary load shedding during emergency and N-2 contingency plans. This enables Aggregated Energy Management services like the one provided by EnerNOC which chiefly provides demand response services that maintain real-time balance between electricity supply and demand. This energy management services provide solutions for energy conservation and efficiency.

It can determine when power supply usage exceeds predetermined value such as contracted load, record and count the number of such occurrences, and send alert notice. Depending upon the existing contract, supply can be disabled. This protects the user from equipment overload. This provides distribution utility better Energy Planning Management (EPM) and improves operation.

(6) Energy prepaid

It can provide prepaid service options which allow users to better manage their energy consumption and optimise their budget allocation without the usual problem of accumulated unpaid bills. Utility in return can provide “pay-as-you-go” special rates since utility gains from advance payment for future consumption and simplified billing and collection operation. Utilities will also be insured of receiving payment from all customers, regardless of income levels.

(7) Power quality monitoring and control

It can detect, record and communicate notices on abnormal power quality beyond acceptable standards. Power quality monitored includes over and under voltages. Recent development in smart meter application includes Conservation Voltage Reduction (CVR) or Volt/VAR optimisation during peak periods that does not affect the performance of the equipment and appliances. This feature achieves not only the peak-shaving potential or the reduction of the peak load requirement of the grid but also lessens consumer energy consumption without sacrifice or involvement on his part.

(8) Tamper and energy theft detection

It has security features that can detect any attempt of unauthorised physical access through its secure perimeter casing. It can provide evidence of such an attempt through the use of tamper evident coatings or seals. When reasonably practical, it can generate entry in its Security log and can send an alert notice via its available interface and disable the supply.

It has also security features that can detect and prevent, on all of its interfaces, unauthorised access that could compromise the confidentiality and/or data integrity of personal data, security credentials, firmware and other data essential for ensuring its integrity. Any such detection can generate entry in its Security log and can send an alert notice via its available interface. These features will deter power theft and drastically reduce non-technical system loss and consequently improve overall system efficiency.

45 http://en.wikipedia.org/wiki/EnerNOC#Notable_work
(9) Communications with other intelligent devices in the home

It can establish open standard bi-directional communication links via each of its interfaces including consumer devices and microgeneration meters over the Home Area Network (HAN) interface and WAN interface. Microgeneration is home-based Renewable Energy power source such as microwind turbines and rooftop solar panels. This feature enables real-time demand response and as a consequence more dynamic pricing schemes.

It includes security features that authenticates the source, verifies the recipient and the command and validates its content and format. The WAN interface can be in the form of any of the following technology depending on its availability as well as practical and technical considerations:

- Power Line Carrier (PLC)
- Broadband over power lines (BPL)
- Copper or optical fiber
- Wireless (Radio frequency), either centralised or a distributed mesh
- Internet
- Public networks (landline, cellular, paging)
- Combinations of the above

B. Smart Grid Issues on Smart Meter

Electronic meter deployment has always the advantage of having class accuracy higher than electromechanical meters. Smart Meter, being an electronic meter would have percent error in accuracy of ±0.2% or ±0.5% against the latter’s ±2% error. A more detailed comparison on the use of Smart Meter versus an electromechanical meter is shown in Table 10.

<table>
<thead>
<tr>
<th>FEATURES</th>
<th>ELECTRONIC (SMART METER)</th>
<th>ELECTROMECHANICAL METER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent (%) Error</td>
<td>±0.2 % or ±0.5 % Error</td>
<td>±2% Error</td>
</tr>
<tr>
<td>Lowest power it can register</td>
<td>5 watts</td>
<td>24 watts</td>
</tr>
<tr>
<td>Re-calibration</td>
<td>None*</td>
<td>Every 5 to 15 years**</td>
</tr>
<tr>
<td>Meter pilferage</td>
<td>None</td>
<td>Rampant</td>
</tr>
<tr>
<td>Standard Expected Useful life</td>
<td>10-15 years</td>
<td>Usually more than 15 years</td>
</tr>
<tr>
<td>Tolerance to weather exposure</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

*Electronic meter calibration use factory setting within ±0.5 % error or lower without need of re-calibration.

**Electromechanical meter slows down after years in the field caused by wear and tear of the mechanical parts

---

Table 10 shows that the smart meter is more accurate than the electromechanical meter. Even during calibration, the latter consumes a lot of time and resources. The old technology limits the accuracy and oftentimes, technicians will settle for less accuracy to achieve the daily volume. The smart meter is not only more accurate but also remains accurate while on the field and does not need calibration. Electromechanical meter needs to be checked and re-calibrated periodically due to wear and tear of mechanical parts. Utility experience shows that meters in the field are much slower when they are checked and can go even lower than -2.0%. Just -1.0% error means automatic 1% less in revenue.

When using the old technology, there is additional operation and maintenance cost in the periodic removal, testing and calibration of the meters. Field work in the Utility Operation is often the least productive activity since the crew loses much productive time and costly vehicle and equipment resources just by traveling in and out of office to find and work in the customer’s premises.

Electromechanical meters will only start to register load higher than 24 watts. For example, 3 units of compact fluorescent light (CFL) bulb rated at 7 watts can be turned on 24/7 and the meter will not register a single kilowatt-hour. Smart meters on the other hand will register load of only 1 unit of CFL. Electric usage of most home appliances on standby and phone chargers will not be registered by an electromechanical meter.

Since a smart meter is solid-state and factory pre-calibrated, it requires a very high technology and sophisticated equipment to pilfer or slow it down. The technology is beyond the reach of common pilferers. Any pilferage will therefore be perpetrated external to the meter and can be easily verified and discovered.

While the smart meter has an expected useful life of 15 years, electromechanical meters are known to be sturdy even when exposed to the weather, and will last more than 15 years. For example, GE I-70 S\textsuperscript{47} which was manufactured in the 1970s is still a standard meter for most homes around the world. However, there are plenty of meter manufacturers in Asia that will not be that durable and will only be accurate within 25 years. Smart meters can well compensate the shorter lifespan with its better accuracy and the additional features it provides. It is therefore recommended that smart meters be provided a meter casing or housing and it be installed in more secure areas.

2.5.2. Electric Vehicles (EV) and Supporting Infrastructures\textsuperscript{48}

At the start of 1970's, environmental impact of the petroleum-based transportation vehicle, along with increasing oil prices, has led to renewed interest in innovative transportation technologies. EVs are destined to be commonly used in the future due to its low impact on environment and noise compared to conventional vehicle or internal combustion engine (ICE) vehicles. These EVs will use batteries that can be charged whether at home or public areas. Availability of electric vehicle charging stations is an important element in promoting EVs. Power utility distribution like PEA and MEA will be another important element in providing the infrastructure for public charging stations. Smart Grid technologies will play a key role in maintaining not only the reliability of the power system but also incorporate demand response mechanism and putting tariff incentives for

\textsuperscript{47}GE model number uses the year it is manufactured. There are still GE I-30 meters working perfectly even after 80 years it was manufactured

\textsuperscript{48}Development of Fast Charging Station for Thailand, Prakornchai Phonrattanasak, Member, IACSIT, and Nopbhorn Leeprechanon
charging the EVs during off-peak and avoiding charging during peak hours. Thailand is slowly but surely moving towards integrating EV in the transport system and providing the necessary power distribution utility support. MEA already purchased several EVs and charging devices in 2012 to promote EV and provided infrastructure for several charging stations of PTT Pilot EV charging stations within their franchise area.

A. Types of EV

There are two types of electric vehicles that are of special interest for Smart Grid technology namely; battery electric vehicle (BEV) and plug-in hybrid electric vehicle (PHEV).

(1) Plug-In Hybrid Electric Vehicle (PHEV)

A PHEV has the characteristics of both a hybrid electric vehicle (HEV)\(^{49}\) which has an electric motor and an internal combustion engine (ICE) and an all-electric vehicle having a plug to connect to the electrical grid (See Figure 38). PHEV could get more than 100 miles per gallon while the vehicle runs primarily on the battery compared to the 30 to 55 miles per gallon that most of hybrid electric vehicle achieves at a charging.

A plug-in hybrid’s all-electric range is designated by PHEV-[miles] or PHEV-[kilometers] in which the number represents the distance of the vehicle which can travel on battery power alone. For instance, a PHEV-32 can travel 32 km without using its combustion engine, so it may also be designated as a PHEV 32 km. EV charging stations will recharge its battery at low electric current.

\(^{49}\) Hybrid Electric Vehicles are not plugged in to electric power source
(2) Battery Electric Vehicle (BEV)

The Battery Electric Vehicle (BEV) or pure EV is a type of electric vehicle that uses only a rechargeable battery (see Figure 39). A BEV or all-electric vehicle uses electric motors and motor controllers for propulsion, deriving all power from its battery. BEVs differ from fossil fuel-powered vehicles in that the electricity must be supported by electricity from the power distribution system.

![Figure 39. Inner Driving Equipment of BEV](http://winarco.com/toyota-iq-electric-vehicle-release-next-year/)

BEVs need more electric power to recharge battery. As the number of BEV increases, the number of charging points will have to increase as well. The Nissan Leaf is a full electric car, which is using 100% of its power on electricity. It runs about 200 km and it is currently sold in Thailand. Mitsubishi Motors Thailand has agreed to start the testing of i-MiEV with the MEA and PEA ENCOM International Company.

B. Supporting Infrastructures for EVs

(1) Charging Station Level I

Level I charging station can be plugged in a household socket which takes approximately 8 to 10 hours to charge the vehicle. Level I is typically used for charging when there is only a home electric outlet available. Based on the battery type and vehicle, Level I charging adds about 2 to 5 miles per hour of charging time. This type of charging is slow, time consuming and unable to meet the need for emergency charging. In Thailand, charging station Level I will have a voltage of 220 V and vehicles can be plugged into standard outlets at home, as specified by the Engineering Institute of Thailand.
(2) Charging Station Level II

Level II requires installation of home charging or public charging equipment and a dedicated circuit of up to 80 amps, depending on the BEVs or PHEVs requirements. However, most residential Level II will operate at lower power because Level II can easily charge a typical EV battery overnight. Level II equipment also uses the same connector on the vehicle as Level I equipment. Based on the battery type and circuit capacity, Level II adds about 10 to 20 miles of range per hour of charging time, depending on the vehicle. In addition, electric vehicles are required to have an interlock deactivating the ignition should anything disrupt the connection. For instance, when a user releases the connector latch, the power flow to the vehicle will immediately stop. The disadvantage of Level II is it has a low range for use in the battery of PHEV or BEV. In Thailand, charging station Level II will have a voltage level of 220 VAC or 380 VAC (3 phase) with protection equipment.

(3) Charging Station Level III or Fast Charging Station

Level III fast charging stations will charge EV in less than one hour. Level III stations rely on an off-board charger that converts AC to DC, using three-phase electric service. Level III refers to direct current (DC), or “fast charging”. To achieve a very short charging period of time, Level III chargers can supply very high voltages (300-500VDC) at very high currents (125-250 A). It needs more electric power and more complex control circuits. It is designed for about 60 to 80 miles of range in 20 minutes of charging. DC Fast Charging will be more suitable than Level II in such locations because EVs customer will expect the shortest recharge time available to minimise travel time.

Fast charging stations should then be installed along the street like gas or petrol station while connected to the electric power distribution grid in Figure 40. However, it must ensure the availability of supply for EVs consumption. The advantage of fast charging stations is it provides a larger service area for BEVs that could charge more vehicles at a time. However, it requires high investment costs for many fast charging stations to cover a service area. The high cost of installation for fast chargers is compensated by the larger number of BEVs charged at a time. In Thailand, a charging station Level III will connect to the power distribution system wherein power will be supplied by MEA for Bangkok, Nonthaburi and Sumuthprakarn province, and by PEA for the remaining provinces.

(4) Battery Switch Station

Battery switch station is a place to swap a discharged battery and recharged battery. The spent battery is taken out and replaced with one that is fully charged. Automated battery-switching station can complete a battery swap in less than one minute. The entire process takes less than five minutes while driver may remain in the car throughout the process. Battery swapping is common in warehouses using electric forklift trucks to exchange battery. In a battery switch station, the driver can wait in the car while the battery is swapped. Electric vehicle manufacturers that are working on battery switch technology have not standardised on battery access, attachment, dimension, location, or type for today. Smart system of battery switch station is programmed to speed up or slow down recharging automatically for optimum charging process to extend battery life span and performance.
2.5.3. Customer Power Management

The choices the customer makes will impact everyone associated with the Smart Grid. Building a Smart Grid will require strong customer power management with strict standards. This means implementing Demand Response (DR) and DR systems beyond the meter into customer homes and industries. This requirement is driven by:

- Energy supply limitations
- Public resistance to building large generating plants
- Environmental pollution and greenhouse gases
- Opposition to siting transmission lines
- Anticipated demands for electricity by electric vehicles
- Distributed generators (DE/RE - sources such as wind and solar panels)

DR uses incentive-based and indirect methods for controlling how much electricity is consumed during a specified time interval by water heaters, air-conditioners, and industrial equipment. The more innovative methods of load control depend on market forces for exerting control by varying the price of electricity.

Demand response technology will involve utilities, third-party suppliers, home network developers, and appliance manufacturers. An example of a third-party demand response service provider is an aggregator serving a large building or neighborhood. They will control the energy requirement of the building with demand response management and install gateway, energy management controller, and HAN devices.
A critical factor for customer power management is the ability for customers to be well informed and have economic standards associated with production integrated with energy. Energy utilities can play a vital role in customer management by informing and advocating the products and devices integrated into the Smart Grid. The utility is ultimately responsible for the service of energy to the customer and has interest to safeguard the grid for delivery if its energy. The energy utilities deal with many suppliers of industrial and business products, in the consumer product industries. Utilities deal with many suppliers of industrial and business products, but most have not cultivated relationships in the consumer product industries. Utilities like products that match with their grid and can motivate manufacturers to design and market them in their customer service area.

It is estimated that the annual market for Smart Grid electronics is almost $200 billion\textsuperscript{50} and for home appliances is about $25 billion\textsuperscript{51}. Both markets include hundred of manufacturers that produce thousands of new products each year. Thus, there are many options for negotiating product specification adapted for energy management provided there is motivation from public policy and from utilities.

As with any new mechanism to incentivise efficiency and implementation, incentives should be incorporated to enable market input and risk mitigation. Since the EU is encouraging the Smart Grid, it is critical to send the right signals to the manufacturers, utilities and consumers. There have been some new laws that were passed that incentivise and regulate the production of electricity from renewable energy sources. Specific EU tariffs have been incorporated by each country in Europe that is encouraging Smart Grid development. The laws and incentives are normally valid for 10 years and may be extended for 10 more years under conditions. The tariffs are normally revised annually.

### 2.6 GENERAL COMPONENTS

Perhaps one of the greatest barriers to Smart/Intelligent Grid deployment is the lack of consistent and predictable access to electric and thermal grids. There is a strong requirement for a defined and predictable process and schedule as well as technical standards. In addition, the permitting process to construct new Smart Grid generation is somewhat unclear. The other general components necessary for a Smart Grid system to work successfully are further discussed in this section.

#### 2.6.1. RET and DER Integration–Interconnection Standards

Interconnection to the electricity transmissions and distribution system is a key element of any electrical power system that is intended to operate in parallel with the centralised electricity system. Interconnection standards for central generation have been developed by most Organisation for Economic Cooperation and Development (OECD) countries in an attempt to address the technical difficulties associated with grid connection. Not all impacts of new generation on the grid can be overcome by technical standards, however. Specifications detailing the maximum new generation capacity that can be installed on a section of the network are not usually provided. It is up to the Distribution System Operator (DSO) to manage such issues to ensure the reliable operation of the network. DSOs are generally not required to make special provision for the installation of DER. If an upgrade to the network is required the cost of this will be often passed on to the DER installer.

\textsuperscript{50} Market size per Consumer Electronics Association (www.ce.org).

\textsuperscript{51} Market size per Hoovers, a D&B Company (www.hoovers.com).
However, efforts have been made to alter this situation. For example, utility and DSO Con Edison (ConEd) in the State of New York are now required to ensure that its network can accommodate DER with up to 2 MW capacities. If any additional upgrading is required, this is entirely the responsibility of ConEd.

Work is also being done in the EU to simplify the interconnection process for renewable and decentralised energy systems. The directive contains measures intended to promote this. Also, the International Council on Large Electric Systems (CIGRE) working group is currently attempting to harmonise the interconnection process of many EU states.

Generally, DSOs require installers of distributed energy (DE) to apply for an interconnection (except in some cases involving very small capacity DE). Typically, a study will have to be carried out to determine whether the DE installation is feasible given the characteristics of the network at the point of connection. The DSO may grant an interconnection for the scheme outright, possibly with restraints or requirements (such as installation of control equipment or network strengthening) or may reject the application. Some DSOs provide a fast track application process for DE that meets the necessary requirements. However, larger installations (typically above a few megawatts) will normally have to undergo a full study.

The connection of the DE system to the grid presents no significant technical issues at all. Nonetheless, the challenges faced by new DE projects throughout the world in securing connection on a fair, transparent and timely basis can be immense, given the resistance often shown by grid operators to DE development. For this reason, the use of interconnection standards that provide clear and independent frameworks for connection are a critical requirement in enabling new DE projects to move forward.

2.6.2. Distribution Network Design and Operation Topology

A transformer steps down power delivered from the central generating facility by high voltage transmission lines to medium voltage. The primary distribution network delivers this power to local loads via medium voltage feeders. Radial feeders are the simplest form of circuit, where power is delivered to the load and stepped down as required. Typically used to supply rural loads where density is not particularly, radial feeders can disconnect many customers if there is a fault. In urban areas, a greater effort is made to provide redundancy to prevent faults from causing complete outages. Multiple feeders are used to supply a low voltage secondary network, so if one feeder experiences a fault the other(s) will still be able to supply the load, preventing an outage.

Distribution networks were originally designed using the principle that voltage would only be applied to the network from a single direction and that power would flow in one direction only. The use of new DE on distribution networks disrupts this principle. A number of technical issues are presented by DE interconnection; the most important of these are discussed in this section including a summary of some relevant examples from various countries’ experiences.

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52 China WADE Handbook; Pg: 123, 153 - 156
A. Technical Issues on Distribution Network Topology

(1) Voltage and Voltage Control

It is necessary for DSOs to maintain voltage on the distribution network at approximately +/- 5 -10% of the nominal rated voltage of the network. To achieve this, voltage monitoring and regulating equipment is installed at key points in the system (see Figure 41). The capacity of DE that may be installed at a particular point in the network is generally related to the voltage level of the network at that point. As higher voltage lines are designed to carry greater levels of power more DE can be installed.

Conflicts can arise in the Smart Grid and DSO attempts to regulate voltage on the distribution system. The Smart Grid thru the integrated software and communication devices installed in the system can modulate the voltage and control the grid automatically thereby decreasing operator error and increasing efficiency. For example a generator may attempt to regulate voltage in opposition to DSO devices or generation may change too quickly for standard voltage regulation equipment to respond. Voltage regulation issues impose the most limiting constraints upon the amount of DE that can be installed on a distribution system because, generally speaking, the greater the DE capacity on a feeder the more difficult it is to maintain the nominal system voltage.

Figure 41. Voltage Control of Transmission and Distribution Network
(Source: http://www.iitk.ac.in/infocell/Archive/dirmar1/power_distribution.html)
Reactive power is also an issue. DE connected to the distribution network will alter the reactive power flow on the network. This will have an effect directly upon the voltage. To minimise these effects standards are set and DSO will typically specify operating parameters for DE power factor. Capacitor banks are usually set up and can be used to correct the power factor of DE installations that absorb reactive power. The smart/intelligent controls for the DE and grid can automatically modulate this voltage.

Induction machines and line commutated static converters can only operate with a connection to the grid. Synchronous machines and self-commutated static converters can operate off-grid. Most off-grid generation is provided by synchronous machines as they can be easily configured to regulate their output voltage. Self-commutated static converters can be fitted with voltage regulation equipment to allow the supply of off-grid loads. The various characteristics of generators are summarised in Table 11.

### Table 11: Characteristics of Different Types of Generating Equipment

<table>
<thead>
<tr>
<th>Type of Generator</th>
<th>Effect on Network Voltage</th>
<th>Effect on Fault Level</th>
<th>Able to Operate Off-grid</th>
<th>Able to Operate in an Islanded Condition</th>
<th>Harmonics Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synchronous Machine</td>
<td>Can increase or decrease voltage depending upon mode of operation. (manageable if power factor kept close to unity)</td>
<td>Large</td>
<td>Yes</td>
<td>Yes</td>
<td>Very low</td>
</tr>
<tr>
<td>Induction Machine</td>
<td>Will decrease voltage (manageable if correcting capacitors are used)</td>
<td>Low</td>
<td>No</td>
<td>No</td>
<td>Very low</td>
</tr>
<tr>
<td>Self Commutated Static Converter</td>
<td>Will have no affect if an automatic power factor control system is fitted</td>
<td>Very low</td>
<td>Yes</td>
<td>Yes</td>
<td>Significant</td>
</tr>
<tr>
<td>Line Commutated Static Converter</td>
<td>Will have no affect if an automatic power factor control system is fitted</td>
<td>Very low</td>
<td>No</td>
<td>No</td>
<td>Significant</td>
</tr>
</tbody>
</table>

The technical issues associated with the Smart Grid are implemented through the use of interconnection standards. Figure 42 illustrates how the protection equipment should be placed. Note that the arrangements in this diagram can also be generally applied to the other interconnection standards.
(2) Fault Protection and Fault Clearing

It is necessary and critical for the Smart Grid or mini/micro distribution system to have the ability to disconnect sections that experience short circuit conditions (overhead cable breaking or accidental excavation of an underground cable). In order to protect the system, automatic circuit breakers and fuses are installed throughout the system.

In order to be placed successfully on the distribution network it is necessary for DE to be able to integrate with existing DSO protection systems. The presence of DE on a feeder can cause power to be supplied to a faulty part of the network unless the DE is disconnected in line with the DSO protection scheme. DE can also affect the automatic re-closing procedure, if the DE has not automatically disconnected before the reclosure takes place, the system may trip again prolonging the outage.

Similarly with fault levels: these are a measure of the current, which would occur in the event of a short circuit at that point. Changes to the network such as the connection of new generators or loads can cause increases in fault levels, which may require an upgrade to equipment to reinforce the network near the point of connection.
(3) Harmonics

The Smart Grid will measure the total demand on the system and integrate small-scale generation as needed. It is necessary to maintain system frequency across the grid by matching the demand of electricity to supply in real time. Any mismatch will cause destabilisation of system frequency. DE should have no real effect upon this due to the relatively small levels of generating capacity associated with each unit. Small-scale DE installations can add harmonics to the fundamental frequency and cause voltage flicker which can reduce the overall quality of the local electricity supply. Power quality is an increasingly important issue as the portion of electrical load that is made up of sophisticated electronics is increasing. The Smart Grid controls will automatically reduce and increase voltages and frequency to maintain harmonics in the system decreasing the flicker in voltage.

(4) Islanding

In the event of planned or unplanned grid power loss it is necessary for an islanding situation to occur whereby a lone generator is left supplying power to the de-energised grid system. It is necessary to have the capability to detect if operating in an islanding mode and disconnect from the grid automatically or there is a risk of losing the entire grid.

B. Examples in Addressing Distribution Network Topology Issues

(1) United Kingdom

In the United Kingdom, the G59/1 engineering recommendations developed by the UK Electricity Association provide the technical guidelines for UK interconnection arrangements. G59/1 covers the requirements for connection to the public distribution system at below 20 kV for generators greater than 6.4 kW in size but not exceeding 5 MW. Devices with less than 6.4 kW capacity are classed as micro-generation and less stringent interconnection requirements for these devices are provided in the G83/1 engineering requirement. The primary focus of G59/1 is the protection requirements for an interconnection, with respect to fault levels and system contingencies. No provision is made for voltage control and power factor requirements.

The DE must be disconnected in the event of a network contingency so that the DSO fault clearing procedure can be carried out; these are indicated by abnormal voltage and frequency conditions. G59/1 also requires DE to disconnect in the event of reverse power flow. Parameters for necessary fault clearing times are specified for DE disconnection. These must be adhered to in order to prevent re-tripping during an automatic network breaker re-closure.

The G59/1 standard requires that protection equipment be installed to automatically disconnect the DE in the event of abnormal network frequency and voltage conditions. The European system frequency is 50 Hz. Thus, they operate under the following guidelines:

- Abnormal voltage: +15% and –10% of system nominal voltage, with a fault clearing time of 0.5s.
- Over frequency threshold: 50.5 Hz, with a fault clearing time of 0.5s.
- Under frequency threshold: 47 Hz, with a fault clearing time of 0.5s.

A caveat is added to these requirements stating that any generator above 150 kVA may need additional protection.
(2) Germany

In Germany, two sets of interconnection requirements exist – one for DE connected to the low voltage distribution network and another for connections to the medium voltage distribution network. For interconnections to low voltage networks, compliance to the DIN VDE 0100-551 standard is required. For interconnections to medium voltage networks compliance is required according to the “Bau und Betrieb von ÜbergabestationenzurVersorgung von Kundenausdem-Mittelspannungsnetz”.

In low voltage grids, a power factor from 0.9 leading to 0.8 lagging is tolerated for the complete electrical system of the customer. At medium voltage, regulation requires a power factor from 1 to 0.9 lagging which is stricter than the requirement for low voltage DE systems. In low and medium voltage grids, generators with strongly fluctuating reactive power need an automatic capacitor-based compensation system. The capacitors must not be connected to the grid before the generator. They must also be disconnected at the same time, since this could affect network voltage levels.

Protection has to be provided to disconnect the generator in the event of a DSO side failure so that the DSO fault clearing process can function correctly. DSO side faults are detected by abnormalities in network voltage and frequency. It is necessary for a DE connected to the low or medium voltage network to be fitted with equipment that disconnects the generator in the following situations:

- DE must be disconnected if a voltage less than 85% of nominal voltage is detected.
- DE must be disconnected if a voltage greater than 115% of nominal voltage is detected.
- DE must be disconnected if a frequency less than 49.8 Hz is detected.
- DE must be disconnected if a frequency greater than 50.2 Hz is detected.

For DE connected to the low voltage network, a standardised automatic disconnection device, known as ENS may be fitted. This device observes the network voltage and frequency levels. If the continuously measured values are out of the ranges specified above then the unit disconnects the DE automatically.

In low voltage grids, for larger systems and systems with a synchronous generator the disconnection time of the protection unit must be shorter than the re-closure time. As an alternative, protective measures for the re-closure must be provided. In medium voltage grids, the operator of the DE unit has to take care that the unit cannot be damaged by an auto re-closure. In low voltage grids, the requirements of the EN61000-3-2 or EN61000-3-12 standards must be met.

(3) UK DSOs

The UK distribution code requires all UK DSOs to follow the decision process detailed in Figure 45. The process details all of the processes that take place when an interconnection application is made.

Different interconnection requirements exist for different scheme sizes. Any scheme with capacity 16 Amps per phase or less is covered by the requirements detailed in G63/1. Installations greater than 16 Amps per phase but less than 50 MW are covered by G59/1. Installations greater than 50 MW must be dealt with on a national level as part of the central planning process.
Figure 43. UK Interconnection Application Process
(Source: Distributed Generation Connection Guide, Energy Network Association
http://www.ppaenergy.co.uk/web-resources/resources/e28a57c7978.pdf)
C. Scales of Smart Grid Systems

(1) Local, Mini and Micro Grids

Local, mini and micro grids are low voltage, small-scale versions of the centralised electricity power generation system. They smaller grids are can operate with or independently the central grid. These are able to function independently in case of disruptions from the centralised grid. e.g. during power outages, brown and blackouts. The electricity may come from any source (reciprocating engines, fuel cells, microturbines, and small-scale renewable generators connected to a grid and dispatched by the DSO. The energy balance has to be maintained and non-critical loads might be curtailed or shed during times of energy shortfall. The micro grid is normally connected to the macro grid and is capable of operating independently under circumstances identified by the DSO.

The local, mini and micro grid if connected to the main grid must adhere to the connections standards. The primary benefit of the local grid is the capacity of local generators for the recovery of waste heat by combined heat and power (CHP) sources. Small-scale thermal generation of electricity is unlikely to be competitive with central station generation. The dramatically improved prospects for useful waste heat recovery, especially in absorption cooling systems, can tip the economic scales towards the local small-scale grids. Since it is easier to transport electricity rather than heat, local and micro grids are usually located around heat loads.

The micro grid if designed properly can maximise efficiency, reduce congestion during peak load, and offset new generation that may be dangerous to the environment.

(2) Industrial Smart Grid Applications

Electricity sent along the utility grid is about 27% efficient and 65% of this fuel is lost as waste heat, a byproduct of generation. Another 8% or so is lost along transmission lines. The use of small-scale or industrial DE limits these losses by eliminating transmission losses and utilising the waste heat from the DE for heating or cooling purposes. Not only does this save energy otherwise lost up the smoke stack, it also reduces onsite energy demand. Several functions can be powered by waste heat rather than electricity or natural gas: steam generation, process heat, building heat, and process cooling. The most efficient systems have high thermal loads relative to electric loads, and can achieve up to 80% efficiency. DE and CHP minimises the distance electricity has to travel between generator and end-use, so very little is lost during transmission. Installing a DE/CHP system is an expensive capital investment, but yields substantial energy savings. Like boiler systems, there are several fuel options that work well with DE/CHP, so some businesses can achieve even further cost savings using waste products such as methane or biomass instead of fossil fuels.

For many businesses and utilities, CHP has another important advantage: reliability. Since electricity is generated onsite, supply disruptions in grid power will not interfere with operations or building systems. In effect, CHP can act as backup generation. Given the high cost of disruptions to most manufacturers, the indirect benefit of increased reliability can be almost as significant as energy cost savings. CHP system consists of three basic components: a prime mover, an electrical generator, and a heat recovery unit.

Common technologies for DE include reciprocating engines, steam turbines, combustion turbines, and combined cycle combustion turbines. Microturbines, fuel cells, and Stirling engines are newer technologies that have begun to appear on the market, although they account for only a small percentage of all CHP systems. CHP systems can also work by capturing waste heat from...
an industrial process with high thermal loads, such as metal casting or smelting. This is known as bottom-cycle CHP. A heat recovery steam generator produces steam from the waste heat, which is used to power a prime mover and electrical generation. Other CHP configurations are combined-cycle (both topping and bottom cycles are interconnected) or trigeneration in which electricity, heating, and cooling are all generated from a single fuel source.

### 2.6.3. Information Communication Technology (ICT) and Wireless Technology

Over the past decade, advances in the telecommunication industry have had a major impact in every industry. In the past decade, the electric power industry started to invest and reengineer the power systems to fully integrate the wireless technology to meet with the future demand and provide an efficient and environmentally sound power system. Wireless communication can simplify and reduce installation costs because no wiring is required.

Today there are a wide range of wireless technologies available: For example, remote meter reading can be accomplished by incorporating power meters into a wide-area wireless network. A wide area network (WAN) integrated with the Internet can be used for a large-scale power infrastructure. Power line communication (which uses existing electric power wiring) will become widely used for applications such as communication among different pieces of equipment within a single building. The home area network (HAN) can be used to control equipment in the home and eliminate power wastage.

Wireless communications and networking will make economical sense as computing and communication devices are becoming more inexpensive. The computers integrated with the latest cellular, wireless, advanced two-way communication, and satellite systems are required for the smart/intelligent power grid.

The industry, academe and governments have created a framework for the smart/intelligent grids which require high reliable, efficient, safe, and secure devices. The power and communication industry are working to integrate the wireless technologies into the smart grid infrastructure. The following communications are being incorporated into the Smart Grid:

- Wireless in Home Area Networks (HAN), Building Area Networks (BAN), Industrial Area Networks (IAN)
- Wireless in Advanced Metering Infrastructures (AMI), Neighborhood Area Networks (NAN), Field Area Networks (FAN)
- Wireless in Home Energy Management Systems (HEMS), Building Automation and Control Networks (BACnet) and other energy management systems
- Wireless sensor networks, wireless mesh networks, WLANs, WiMax, Cellular, and ZigBee for smart grid

Communication with substations, power stations and remote areas is done more economically with wireless technology. Today it is simply too costly to run wires to remote areas and city locations. Wireless communication, cellular networks, WiMAX, Wi-Fi, can be faster and less costly to deploy. Cell phones, WiMAX, Wi-Fi, wireless data transmission radios have proven to be both cost-effective and secure. These long-range radios offer a high throughput, both upstream and downstream. As far as communication technologies are concerned, distribution automation is a time-sensitive application. A lot of the equipment requires very low latency – meaning the time it takes for control signals or packets to travel across the link and cause the action you intend. These wireless radios especially have high throughput and very fast latency – so they are more suitable for automation for SCADA applications.
The electric grid has been identified as one of the key infrastructure points and there is great potential for a security threat and the evolution of cyberspace has made the electric grid prone and vulnerable to cyber attacks. With the increasing threat of cyber attacks, power communication networks and infrastructure of the electric power grid needs to be protected.

Two of the most common threats to data communication networks today are Denial of Service (DoS) and Intrusion. High levels of computers and intelligence is required to penetrate the Smart Grid however, the power companies must continually upgrade the software and computers. Frequency Hopping Spread Spectrum (FHSS) systems (continuously varies the frequency) -- FHSS wireless systems are very resilient when it comes to attacks (deliberate or coincidental) and jamming. This makes DoS attacks on FHSS systems difficult, however, utilities must always be up-to-date on their security measures.

Many security protocols and industry standards have been established for wireless devices and are being employed into the Smart Grid. Devices like Wi-Fi and WiMAX, have security but a good cyber attacker can easily access these devices since they are off the shelf.

Access Control (only allows network access by authorised personnel or devices) is being employed into the devices to ensure greater security. The verification and authentication is based on unique credentials (hopefully can neither be “spoofed” nor counterfeited). Advanced Encryption Standard (AES) is also incorporated and protects data from the customers. Many of the top government agencies are using these technologies to protect against attacks from outsiders.

Using secure communication technologies for distribution automation can save time and money on the operator’s end. The Smart Grid is a potential target not only to physical attack, but cyber-attacks as well. Today, there are wireless technologies available that not only offer reliable communication to remotely located substations, but that are less vulnerable to DoS and Intrusion type attacks.
PART III

SMART GRID
BARRIERS, STRATEGIES
AND OPPORTUNITIES
PART III

SMART GRID
BARRIERS, STRATEGIES
AND OPPORTUNITIES
The electrical systems in the world are changing and the developed world is integrating some new technology to improve the energy efficiency of the electrical system. Smart Grid is a concept that will save the government, energy companies, utilities, and customer money and resources in the long run. In order to develop and deploy a Smart Grid however, there are many obstacles that must be overcome. This section will discuss the barriers and challenges that are foreseen when transitioning towards a Smart Grid system. It will also identify specific strategies for Thailand to overcome these barriers and discuss the opportunities that the Smart Grid system provides.

3.1. CHALLENGES TO SMART GRID DEPLOYMENT

In every country there are opportunities and barriers to Smart Grid development and deployment. Thailand has a choice between a “business as usual” approach, which commits to conventional fossil fuel and large hydropower, or a move towards a clean, secure, sustainable decentralised energy system. Smart Grid presents an economic and environmental case for making the transition towards a sustainable and efficient energy system.

3.1.1. Major Barriers to Smart Grid System Development

A. Standards and Protocols

Smart Grid requires consistent and well thought out standards. There are many components/technology providers which are involved with the grid offering a wide range of equipment and services (e.g. smart meters, appliances, grid automation software) and they all require communication among each other, therefore protocols must be in place. However, the technology providers are using closed standards that are proprietary. If one component fails the grid will not work. The standards must be implemented by the manufacturer and then checked by the industry.

Another setback stems from some features of Smart Grids which draw opposition from industries that currently are, or hope to provide similar services. An example is the competition between cable and Digital Subscriber Line (DSL) Internet providers from broadband over power line Internet access. Providers of SCADA control systems for grids have intentionally designed proprietary hardware, protocols and software so that they cannot inter-operate with other systems in order to tie its customers to the vendor.

Many of these standards are still under development and it is taking time to get a consistent standard. Smart Grid will only succeed on a large scale if technology suppliers agree to work in an open and regulated standard.
B. Customer Education and Engagement

Consumers, utilities, industry and politicians are normally slow to engage Smart Grid in their domains. Customers are under the impression that the costs will increase and outweigh the benefits as in the past. The utilities and governments need to effectively educate the public of the benefits of this new change.

Most opposition and concerns by consumers have centred on smart meters. Where opposition to smart meters is encountered, they are often taken to be against the “Smart Grid” system as a whole. Specific points of opposition must be threshed out with the consumers to pave the way for Smart Grid implementation. Some of these concerns include:

- Consumer concerns over privacy, e.g. use of usage data by law enforcement;
- Social concerns over “fair” availability of electricity;
- Concern that complex rate systems (e.g. variable rates) remove clarity and accountability, allowing the supplier to take advantage of the customer;
- Concern over remotely-controllable “kill switch” incorporated into most smart meters;
- Social concerns over Enron style abuses of information leverage;
- Concerns over giving the government mechanisms to control the use of all power using activities;
- Concerns over Radiofrequency (RF) emissions from smart meters.

C. Funding and Investment Costs

The developing countries are improving their infrastructure and it has proven costly and the recession which began in 2008 has slowed development around the world. Companies are reluctant to invest large amounts of funds into projects that are considered risky.

Due to high investment costs, most utilities find it difficult to justify installing a communications infrastructure for a single application (e.g. meter reading). Therefore, a utility must typically identify several applications that will use the same communications infrastructure – for example, reading a meter, monitoring power quality, remote connection and disconnection of customers, enabling demand response, etc. Ideally, the communications infrastructure will not only support near-term applications, but unanticipated applications that will arise in the future.

D. Security Concerns

The energy sector is one of the most important cornerstones of the country and there is concern over terrorism (specifically computer hackers). If proper security is not available to safeguard the information and communication, the hackers can turn off/on a Smart Grid equipment which can disrupt the grid and cause major damage.

E. Regulatory Barriers

The utilities and regulators are always at odds since the utilities want to recover the cost quicker than the regulators will allow them. The utilities must provide power to the customers and therefore need to recover the costs that are put into system improvements. Smart Grid requires that the utilities upgrade the infrastructure and the regulators are insisting that the cost be recovered over time thus they apply for rate increases accordingly. The utilities want the customers to pay for the upgrades and the customers do not see the recovery as projected by the government. This vicious cycle is a major barrier.
Regulatory environments often do not award utilities for operational efficiency and this discourages such investment. For example, before a utility installs an advanced metering system, or any type of smart system, it must make a business case for the investment. Some components, like the power system stabilisers (PSS) installed on generators are very expensive, require complex integration in the grid’s control system, are needed only during emergencies, but are only effective if other suppliers on the network have them. Thus, without any incentive in place, power suppliers will not install them.

Regulatory or legislative actions can also drive utilities to implement pieces of a smart grid. Each utility has a unique set of business, regulatory, and legislative drivers that guide its investments. This means that each utility will take a different path to creating their Smart Grid and that different utilities will create Smart Grids at different adoption rates.

### 3.1.2. Barriers Specific to Thailand’s Context

The following is a list of Smart Grid development barriers applicable to the specific context of Thailand:

- Over investment in conventional power plants, which have large line losses;
- An opaque power development planning process that neglects to consider a full range of economic least-cost alternatives, without opportunity for challenge from external stakeholders;
- Regulatory restrictions in the implementation of energy plants in commercial complexes and buildings based on zoning;
- Tariff setting does not reflect the cost of fuel;
- Difficulties in funding (investors and lenders) the projects;
- Lack of organisation providing information, training or services;
- Lack of awareness and knowledge on Smart Grid and environmental issues;
- Getting the regulators to pass the increase in costs for replacement of equipment.

### 3.2. MEASURES TO OVERCOME BARRIERS

The new Smart Grid will integrate digital technology to improve reliability, efficiency, flexibility, and decrease electricity costs to the utility and end users. The will and mechanism to achieve this vision hinges upon activities that directly address the technical, business, and institutional challenges to realising a smarter grid.

### 3.2.1. Key Strategies

The key strategies to overcome these challenges are summarised as follows:

#### A. Interoperability and Standards

Smart Grid devices need to interoperate in a secure environment throughout the electricity delivery system. The ongoing Smart Grid interoperability process promises to lead to flexible, uniform, and technology-neutral standards that enable innovation, improve consumer choice, and yield economies of scale. Activities in the domain of interoperability and standards are not limited to technical information standards; they must be advanced in conjunction with business processes, markets and the regulatory environment.
B. Interconnection Planning and Analysis

It is important to gain greater certainty with respect to future generation requirements, including identifying transmission requirements under a broad range of alternative electricity futures (e.g. intensive application of demand-side technologies) and developing long-term interconnection-wide transmission expansion plans.

C. Workforce Development

Smart Grid implementation could take over two decades and covers everything from power generation, transmission, distribution, regulations and consumers. Electricians, line workers, technicians, system operators, power system engineers, cyber security specialists and transmission planners will have to adapt to the new power systems and integrate the communication devices such as smart meters, phasor measurement sensors and advanced communication networks.

Workforce development must address the impending workforce shortage by developing a greater number of well-trained, highly skilled electric power sector personnel knowledgeable in Smart Grid operations.

D. Stakeholder Engagement and Outreach

Stakeholder engagement and outreach activities are crucial to identify research and development needs for planning, sharing of lessons learned for continuous improvement, and exchanging technical and cost performance data. Information is provided in www.smartgrid.gov to inform decision makers about Smart Grid technology options and facilitate their adoption.

E. Monitoring National Progress

Monitoring national progress activities will establish metrics to show progress with respect to overcoming challenges and achieving Smart Grid characteristics.

3.2.2. Strategies to Remove Barriers in Thailand

Smart Grids have multiple operational mechanisms and have no single shape. Thailand has many opportunities to enhance the grid and provide energy in an efficient and environmentally sound manner. In order to do so, Thailand has to overcome certain barriers and challenges. The following are some recommendations to remove the existing barriers surrounding the development and implementation of Smart Grid systems in Thailand.

(1) Standardise the Smart Grid definitions and interfaces with the government, regulators, and utilities while setting product requirements and applications. The government, regulators, and utilities should create a strategy and develop standards in participation with industry and stakeholders on an international level to ensure interoperability of system components and reduce risk of technology obsolescence.

(2) The government and regulators should collaborate with public/private sector stakeholders to determine regulatory and market solutions that can mobilise private sector investment in the energy sector.
(3) Regulators should create, promote, and adopt a real-time energy usage tariff. Generators, transmission system operators, and distribution companies should plan and operate the systems in a coordinated manner.

(4) Transmission and distribution system operators should work in coordination to develop operational business models with government and regulators, which ensure that all stakeholders share risks, and are shown the benefits of system reliability, cost, environmental sustainability and security.

(5) Generators should be flexible on the methods used by the Smart Grid to meet demand growth and decrease emissions.

(6) Create a mechanism for the utilities to invest in research, development and demonstration. The government should actively engage in developing system demonstrations and deployments in order to ensure consumer contribution to and benefit from future electricity systems and markets, while ensuring consumer protection.

(7) Reform the power planning process so that it becomes an integrated resource planning (IRP) process, overseen by the energy regulator, in which all alternatives are considered (including energy conservation and renewables) and through which utilities are required to choose the option with the lowest overall economic cost to society, as opposed to the lowest commercial cost to the state generator EGAT. Integral to the achievement of this recommendation is the completion of comprehensive assessment of the externality costs of different fuels and generating technologies in the Thailand context.

(8) Introduce feed-in tariffs for specific renewable technologies to encourage deployment.

(9) Change policy to put energy saving at the forefront of the energy agenda and remove the barriers that limit DE.

3.3. SMART GRID OPPORTUNITIES IN THAILAND

Thailand’s government is actively pursuing a nationwide Smart Grid network focusing more on decentralised and renewable energy. Thailand is still dependent on Myanmar and Laos as the main suppliers of hydro electricity, with Laos becoming the key supplier as new hydropower plants come on line. Thailand is also an oil/gas producer, but consumes two to three times as much as it produces. Similar to other South East Asian nations, such as Indonesia and the Philippines, Thailand has opted for a national system of independent and decentralised power production.

Thailand has already initiated one of the most important pilot projects in Pattaya City. PEA, EGAT, MEA are reviewing the 40-year old national grid which may not be sufficient for the new industrialised Thailand. Increased customer demand with industrial growth is prompting a change in the energy mix, which will utilise renewables.

The Thai government has made the energy sector a priority, PEA announced a bold step into the future with Smart Grid Roadmap project on 10th March 2011, and Ministry of Energy appointed the subcommittee on the study of National Smart Grid Development Master Plan on 8th December 2011. The master plan of Thailand Smart Grid Development for the next 20 years (until 2030) is being prepared by EPPO.

Power production and capacity was significantly expanded to meet the expected growth however it is not enough. The growing demand in Bangkok and Nonthaburi (a population of about 12 million)
and the rising manufacturing zones in northern Thailand up towards the Myanmar border require an in depth review of the grid to integrate renewables. The existing transmission equipment and systems are old and underdeveloped by modern means. This opens up great opportunities for Smart Grid deployment.

The opportunities for each Smart Grid key player consisting of the government and regulators, utilities, vendors and consumers are summarised in Figure 44.

![Figure 44. Opportunities and Benefits of a Smart Grid](Source: Accelerating Smart Grid Investment, World Economic Forum 2009)

### 3.4. BUSINESS MODELS FOR SMART GRID SYSTEMS

Many utilities are rethinking the future of electricity after the deregulation in the late 90’s. The electricity industry has transformed into generators, transmitters, distributors, and energy service companies. Some utilities have completely left the generation business and have become just distributors.

The entire power industry through deregulation is looking at several mechanisms of moving into the Smart Grid. Many of the utilities have initiated pilots and secured financing to upgrade the grids.

**Phase 1:** Many of the utilities have initiated pilot projects where they can study and determine the actual requirements for entire cities and their customers. The traditional vertically integrated utility may survive in some places but many utilities will have to venture out to a “wires only” model where they provide distribution services on behalf of energy retailers. Some utilities are moving out to provide energy services on behalf of the utility.

**Phase 2:** Once the utilities are comfortable with the pilot projects they will eventually mobilise the successful ideas into the main grid. Utilities will mitigate risk by merging or creating smaller companies or finding partners who are more capable in distribution and handling communication with consumers. The utilities may look towards the government and regulators to provide incentives for greater development of the power grid and to mitigate the new investment.
Phase 3: After regulatory or government intervention—utilities and energy service companies will probably move into the information technology role of gathering and selling data to large companies like google, yahoo, and IBM. Some companies may find benefits in selling applications to customers to manage the energy like applications on the Iphone.

The electric utilities are accelerating in the upgrading of Smart Grid infrastructure as well as the mechanisms to interact with customers. The upgrades in the customer information systems and software are expected to double over the next five years.

In Europe, the energy retailers are shifting to Computer Information System (CIS) technologies and more on consumer retention and education. The wireless telephone companies, internet service providers and other information gathering agencies are also looking to enter the market in providing the customers targeted information on products and services that can save their money. Companies that offer the new product are offering bundles that will enable competitive differentiation, according to the report. Today, confusion still exists in the market about how and where to apply analytics to improve business outcomes, but the market will mature rapidly as a result of growing commercial pressures.

3.5. RECOMMENDATIONS FOR IMPLEMENTING A SMART GRID SYSTEM

The power industry is changing and calls for a complete switch into the next generation through automation. Thailand needs to begin with basic automation systems eventually upgrading to the advanced systems by 2025. By analysing the growing power demand and market competence, this is one of the ways forward for the power industry to decrease its future costs and reduce their carbon footprint. The implementation of Smart Grid is not going to be an easy task as the power sector poses a number of issues such as minimising transmission and distribution losses, inadequate grid infrastructure, low metering efficiency and lack of awareness. The most important aspects in implementing a Smart Grid system are discussed hereafter, including some specific recommendations to make its development and deployment successful.

Smart Grid systems can have a great impact on the country and it is necessary to map out a proper vision with timelines for implementation. The recommendations are based on several practices in the EU and may be considered for use in Thailand.

3.5.1. Smart Grid Certification

Certification and permitting processes for Smart Grid devices/systems connected to an electrical transmission or distribution network take a number of forms. Tests are required for performance and compatibility to grid. These tests are extensive and are performed in order to confirm that the design of the equipment is sound and that the devices/systems would be expected to perform sufficiently over its service lifetime within the boundaries of the specified operational regime. A much-reduced series of tests would then be performed on all production units of the same design (so-called “routine” testing) in order to confirm that the manufacturing quality of these units is adequate.

It is usual for detailed electrical system modelling to be performed to determine the expected impact of the new smart equipment on the host grid network and vice-versa.
This modelling exercise can also be very time consuming and expensive, but is normally a requirement of the host utility, as well as being an opportunity for the smart generator to mitigate some of the financial risks associated with the potential technical non-compliance of their equipment when connected into an electrical grid network.

A key issue affecting the viability of Smart Grid systems is the cost associated with completing and administering the certification and permitting process. Also, these costs do not generally vary proportionally with sizing of Smart Grid system and they therefore tend to have a much greater impact.

In order to promote and enhance the Smart Grid schemes, there is a strong case for standardised certification and permitting rules for new schemes, pre-defined technical and other requirements (such as cyber security, safety, etc), and that the certification process is administered fairly by approved agencies. Alternatively, compliance with some of the technical performance requirements of the system specification could be verified through manufacturer “self-certification”, reducing the financial burden associated with employing a third party assessor.

The certification process should also be made legally binding as it would also enable developers to assess future schemes on the basis of known and defined technical and certification requirements, thus removing some of the uncertainty that currently restricts investment in Smart Grid applications. Ideally, with suitable electrical interconnection standardisation, the certification of a new design of Smart Grid system, either through self-certification or by an independent third party, would validate this design for application at a wide range of host sites without the need for further extensive type and site testing.

**RECOMMENDATIONS**

- Standardised Smart Grid devices/systems integration certification and authorisation protocols should be developed and implemented;
- System manufacturers should be permitted to “self-certify” certain aspects of the performance of their systems in order to minimise the financial burden associated with the certification process.

**3.5.2. Smart Grid Incentives and Financing**

It is important to generate initial interest in order to stimulate Smart Grid technology and system development. The provision of incentives and financing through policy mechanisms is a traditional way of creating such an environment, and this approach has been deployed very successfully in the past, for example as a means of stimulating renewable energy developments. However, it is important that once the initial market has been stimulated through these mechanisms that technology is commercialised to a degree that it ultimately becomes self-sustainable, i.e. it does not rely on incentives in the long term. This has to be the clear goal for Smart Grid implementation with RE integration.

The installed costs of newer technologies (e.g. Smart meters, automation, Distributed Generation (DG), fuel cells, micro turbines, etc.) are currently too high. The higher cost factor is disabling them to achieve a significant market penetration breakthrough without some degree of cost reduction. Thailand may offer sufficient incentives to enable developments to take place, whilst ensuring that manufacturers are encouraged to develop genuinely “commercial” systems. Typical incentive mechanisms that could be applied to are:
• Grants to offset installation costs
• Tax incentives and rebates
• Priority access to grid
• Compensation payments for avoided network infrastructure costs
• Guaranteed prices or “top-up” payments for exported energy
• Appropriate interconnection requirements and standardisation
• Payments to account for system efficiency improvements
• Carbon Credits for system performance/environmental performance benefits

Each of these mechanisms has its merits and potential drawbacks. Furthermore, the use of incentive mechanisms within the energy sector is a complex issue that is impacted by many variables, many of which are very hard to predict and control.

RECOMMENDATIONS

• A full assessment should be performed to determine appropriate, fair and consistent incentive regimes. These incentives must both encourage the uptake of new technologies and lead to the commercial development of these technologies while enabling them to compete and maintain market share in the long term; and
• Thailand should develop a detailed financial model of the entire power market, with the purpose of enabling the impacts of different incentive schemes on the penetration of different technologies. Such a model will also enable a pro-active response to changes in market structure and technology developments by policy makers through changes in incentives and other mechanisms.

3.5.3. Coordination of Smart Grid Activities

At the current time there are limited activities, both at the long-term fundamental research stage and at the nearer-term commercialisation stage. There is a general lack of cohesion and strategic focus pulling all the research and development activities together in the same direction for the good of Thailand.

In order for this to occur, it is important that a database is kept that monitors the dynamics of the power industry. Such parameters should be systematically recorded and stored in the reliable database system, and should include (amongst other things) up-to-date and continuously maintained information. A key requirement will be to include accurate statistics on the current status of Smart Grid that can be used as the basis for future policy initiatives and research and development funding decisions.

RECOMMENDATIONS

• Thailand should give consideration to the increase of research and development support for Smart Grid technology developments, and the increased developmental funding;
• Given the high strategic importance of developing a successful Smart Grid, an industry research and development coordinating group should be convened to promote the benefits of Smart Grid. It is considered that the best way to achieve this is by setting up such a group in a dedicated “Smart Grid Office” located in Bangkok; and
• This group would be a centre of competence and information on Smart Grid issues for stakeholders; providing a focal point for Smart Grid technology and institutional barrier removal; providing guidance for the coordinated and directed support of Smart Grid technology development support; and continuously maintained database of the power sector and Smart Grid statistics that could be systematically and protectively assessed.
3.5.4. On Feed-in Tariffs

As a development mechanism to accelerate the Smart Grid implementation and encouraging decentralised/renewable energy, it is recommended to establish feed-in tariffs so that the benefits have time to accumulate. It is also necessary to put in place mechanisms to strengthen the programme in the long term through review/adjustment of tariff levels every two years, and putting in place a stable legal basis on parliamentary law.

RECOMMENDATIONS

- Arrive at mutually agreed upon principles for determining feed-in tariff levels;
- Arrive at mutually agreeable initial feed-in tariff levels for different technologies. The levels proposed by various Thai actors for biomass, biogas, wind power, and micro-hydropower are all broadly reasonable. The levels for Municipal Solid Waste (MSW) and solar electricity may be trimmed;
- Establish a legal basis for feed-in tariffs. In the short term, this could take the form of a Cabinet Resolution. However, work should also be initiated to develop a full renewable energy law to be passed by Parliament in order to provide sufficient long-term assurances to investors that the feed-in tariff program will be in existence long enough to justify investment;
- Generators to have guaranteed access to the grid (already partially in place);
- Capacity and the authority to levy fines; and
- Conduct externality study.

3.5.5. Improve the Regulatory and Policy Framework

Thailand authorities should take the lead and develop specific policy documents and regulations on cyber security and privacy of the Smart Grid in order to improve the regulatory and policy framework. Thailand may want to review the European security protocols for Smart Grid development and take into account existing regulations and policies on Smart Grid, challenges, goals and needs of cyber security for the grid.

RECOMMENDATIONS

- Define security measures to be considered in current Smart Grid deployments (e.g. smart meter roll-outs);
- Demand grid operators for security risk assessments;
- Demand manufacturers, integrators, services providers and grid operators to comply with specific security certifications;
- Establish regulatory pressures (e.g. fines) for not complying with the rules and regulations; and
- Demand operators to report on cyber security related incidents.

3.5.6. Customer/Manufacturer and Utility Awareness

The understanding of consumers, utilities and manufacturers on how power is delivered to their homes is very significant. Before implementing Smart Grid concepts, Thailand may consider educating the public about the Smart Grid, its benefits and contribution to the economy. Consumers, utilities and manufacturers should be made well aware about their energy consumption pattern.
Utilities, staff of grid operators, electricity services providers, and manufacturers should be made aware of their responsibilities related to the importance in Smart Grid. Training initiatives may be created for manufacturers on how to build secure devices and applications, for grid operators and customers to be trained on the utilisation of these devices, which will in turn affect the security of the grid.

PEA, MEA, EGAT, EPPO, DEDE and ERC needs to focus on the overall capabilities of Smart Grids rather than mere implementation. Policy makers and regulators must be very clear about the future prospects of Smart Grid.

RECOMMENDATIONS

- Enhance communication among Customers and the Utility;
- Organise technical events for raising awareness and training;
- Prepare appropriate media for raising awareness on Smart Grid security aspects;
- Define a clear and unified strategy for ongoing and new initiatives;
- Identify Smart Grid initiatives;
- Set up a centre of excellence for Smart Grid; and
- Define system-wide technical terms.

3.5.7. Coordinate large/small scale energy integration into the Smart Grid

For Thailand to continue along its path of aggressive economic growth, it needs to build a modern, intelligent grid. It is only with a reliable, financially secure Smart Grid that Thailand can provide a stable environment for investments in electric infrastructure. Thailand authorities should consider a study/strategy to coordinate the integration of renewable/decentralised energy into the grid. This integration will affect the grid stability and security. They should study the convenience of a central coordinating entity for the grid and also the small mini/micro grids that may develop as a result of the new renewable and decentralised energy policy.

Power disruptions may impact the grid and customers will not be happy. Therefore, in order to develop strategies for handling incidents, different stakeholders will have to be involved, ranging from electricity generators to consumers, and at all levels, from infrastructures to services and operations. Structures and mechanisms should be in place, at the organisational and coordination level, and the technical level should be considered. International experts agree that Transmission System Operators (TSOs) and Distribution System Operators (DSOs) need to be the ones performing monitoring actions to detect possible disruptions affecting the power grid as a whole. Many experts consider that TSOs should be the organisations in charge of monitoring and triggering alarms.

PEA, MEA, EGAT, EPPO, DEDE and ERC needs to focus on the technical capabilities of Smart Grids.

RECOMMENDATIONS

- Security monitoring sensors should be distributed across the grid gathering data that could be processed in a decentralised or centralised manner;
- A central monitoring centre for data collection and analysis may be created/adopted;
- Signature-based software will be needed in sensors;
- Monitoring centres could also perform research activities (e.g. write new signatures, study new grid operating methods).
Scientists, engineers, and policy makers working on energy, together with industry, are in a position to develop a more viable energy market for Thailand in the future. They can adopt and utilise existing resources for the greater demand that is anticipated with growth. This effort will result in the creation of Smart Grid infrastructure, industrial base, specialised research centres, institutional set up, trained and qualified manpower, codes, standards, specifications, regulations, legislations and policy measures, which would facilitate acceptance of the Smart Grid by consumers. This would require an integrated energy system to be developed and put in place and in turn, require continuous development, demonstration and validation of various technologies related policy issues and other measures. Strong Public-Private Partnership Projects would also need to be implemented to achieve this.
PART IV
CASE STUDIES ON EU BEST PRACTICES
PART IV
CASE STUDIES ON EU BEST PRACTICES
As the subject matter of Smart Grid is relatively new, there are many issues and concepts that are considered complex and unclear to many. This section will identify and discuss case studies on best practices in Smart Grid systems in the European Union (EU) with an assessment of their applicability to the Thai context.

The selected case studies on Smart Grid initiatives policies and best practices in EU are namely, the EcoGrid project in Denmark, E-Energy Project - MeRegio in Germany, and the Linky Project in France.

4.1 DENMARK’S ECOCGRID EU PROJECT

Denmark, located in the northern part of Europe with a small population, has embarked on the evolution to upgrade its existing grid to a Smart Grid through its national strategy called Energy Strategy 2050. The strategy points out the need for a well-organised expansion of the power grid and other measures to maintain the security of supply to cope with increased amounts of wind energy and other renewables. Additionally, it promotes the use of intelligent electricity consumption.

4.1.1. Background of Denmark’s Smart Grid Project

Smart Grid solutions are being accelerated through the implementation of demonstration projects. One of such projects is the EcoGrid EU project in Bornholm, Denmark. Earning the distinction of being awarded one of “100 powerful sustainable solutions”, this project was presented to high-level decision-makers at the RIO+20, United Nations Conference on Sustainable Development in Rio de Janeiro last June 20, 2012. The EcoGrid EU project is supported in part by the EU’s 7th Framework Programme on Research, Technology Development and Demonstration. The total budget of EcoGrid EU is €25 million and the demonstration had its formal outset in January 2011.

The concept of the EcoGrid project is best described in the following scenario:

Imagine a green, Smart Grid world. You wake up and your house is already planning its day. Your appliances are talking to you (say, by smart phone app), to each other, and also to the electrical grid, checking on prices and on the availability of clean electricity. Your rooftop solar electric panels have checked the weather to calculate how much energy they’ll produce. They’ve told the dishwasher that the sun is shining so it can go ahead and kick on (when a cloud passes, the panels tell it to briefly cool down). The garden sprinklers know that water supplies are tight, so they won’t turn on until midnight. They’ve also detected a leak and arranged to have it repaired. In the afternoon, as temperatures and electricity demand climb, the solar panels sell electricity back to the electric company for a premium. Grid managers cut a deal with the freezer: they pay it (and innumerable other freezers in town) to postpone defrosting. That helps the grid meet demand spikes without cranking up a fossil fuel power plant. Your plug-in hybrid car knows when there’s extra solar power or cheap, carbon-free wind power on the grid, and that’s when it recharges itself for the next day’s commute. This is the green world EcoGrid EU wants realised!

53 Environmental Defense Fund (EDF) website (http://www.edf.org/energy/smart-grid-overview)
The EcoGrid EU is a large-scale demonstration project on the Danish island Bornholm. The aim is to demonstrate a Smart Grid solution to operate a power system with more than 50% renewable energy, including a mix of variable distributed energy resources (i.e. wind, solar, biomass, biogas, and CHP) and energy storage technologies such as heat pumps, district heating and batteries from EVs. Out of the 28,000 electricity customers on Bornholm, 2000 residential consumers will participate with flexible demand. A major part of the participants will be equipped with residential demand response devices with intelligent controllers, enabling customers to respond to real-time prices and allow users to pre-program their automatic demand-response preferences.

The EcoGrid EU project will demonstrate a market concept designed to incorporate small-scale distributed energy resources and flexible demand into the existing power system markets, balancing tools, and operation procedures. The concept (see Figure 45) will remove the barriers that DERs have previously been facing to enter the present market structure, e.g. requirements on size and online monitoring, and a significant administrative burden including bidding in the markets, complying with schedules, and financial obligations.

The cornerstone in the concept is the introduction of an accessible real-time market solution for small-scale generation, storage, and flexible demand. This can be utilised for short-term, intra-hour balancing, but equally important, also for day-ahead balancing. The markets are extended toward shorter time-scales where the volatility increase, and thereby the possibility for the participant to obtain an economic benefit.

The general concept of this proposal is based on a real-time market approach that lets distributed energy resources and flexible electricity demand receive and respond to variable electricity prices. Soon after clearing, the electricity price from the already well established day-ahead spot market is sent to the end-user. This price acts as a forecast of the real-time price and allows scheduling of assets that require advance planning. In the course of the day the price signal is updated in real-time, i.e. every five minutes, to reflect the need for up- or down regulation due to an imbalance in the power system. If no imbalance exists, the real-time price will be equal to the day-ahead spot price.

The real-time price is set by the Real-Time Market Operator, which might be the TSO, on the basis of the need for up- or down regulation due to occurring imbalance between production and consumption and/or restrictions in the transmission/distribution system.

The price is updated frequently, every 5 minutes, to utilise the potential for a dynamic response. The prices are thereby not determined by the intersection of supply and demand curves, expressed by bids, and consequently, there is no need for the market participants to submit bids. This real-time market overlaps/complements on the one hand the balancing market, which mainly is addressing larger units (several MW), and on the other hand the automatically controlled reserves. The update interval of 5 minutes provides a good compromise between on the one hand, a fast response for balancing purposes, and on the other hand the computational burden and complexity in the settlement process. However, it requires that the meters and the metering data management systems can handle 5-minute interval readings. If this is not considered feasible in a particular replication scenario, the fundamental concept and the infrastructure works equally well with longer intervals, e.g. 15 minutes or 1 hour, though clearly the dynamic response for balancing will be limited by the interval length. This allows the concept to be replicated in areas where e.g. smart meters with 15-minute/hourly readings have already been deployed, and the concept can thereby be adapted to utilise such existing infrastructure.

Because the real-time price is used to level out imbalances that occur relative to the day-ahead schedules the real-time price will to a certain extent follow the day-ahead price. In turn, the day-ahead price represents a good prediction of the real-time price, and this allows end-users
with e.g. longer-term storage capacity (hours or even days rather than minutes) to optimise their behaviour accordingly. Over time, this response to not only real-time but also day-ahead price changes will be incorporated in the demand forecasts, and thereby in the demand bids in the day-ahead market, and consequently introduce demand elasticity in the day-ahead market.

![Figure 45. EcoGrid EU - Concept Architecture](Source: EcoGrid EU A Prototype for European Smart Grids)

### 4.1.2. Salient Features of the EcoGrid EU Project

Smart Grids are considered as one key enabler to achieve Europe’s climate energy policy goals (the 20/20/20 target)\(^\text{54}\). The EcoGrid EU demonstration project is an opportunity to show how an existing energy system with a high share of intermittent and distributed generation can cope with the vast challenges that Bornholm, along with many other regions in Europe and worldwide, will face in the future.

The vast majority of previous and ongoing Smart grid projects have focused on the assessment of the technical possibilities. In contrast, the EcoGrid EU project focuses on market-based system operation, so that both production and consumption should respond to price signals from the power system rather than be controlled directly by system operators. The EcoGrid EU project will develop and make a demonstration of a near real-time market. However, the intention is not to change the current and well functioning electricity market, of which Bornholm is an

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54 The European Union’s climate change package, including 20% cut in emissions, 20% improvement in energy efficiency and 20% increase in renewable energy by 2020.
integrated part. The current electricity market remains and must be used for optimal activation of the consumption side during the demonstration phase. The success of the concept will rely on its capability to interact with the current Nordic/European electricity market. In this respect, the EcoGrid EU project will enter an area where other projects often show only parts of the solution.

The specific best features of this project are outlined and described hereafter.

A. ICT Platform and Technology

Extensive roll-out of communication systems and intelligent metering capabilities (ICT platform and technology) is expected for the segment of small end-users of electricity. This information technology has the potential of enabling demand to respond to market signals, interact with system operation and participate in the system balancing. This development makes it possible to get unprecedented levels of demand response from smaller customers, which can assist balancing systems with high levels of renewable energy sources and change the way power systems are planned, developed and operated. Furthermore, new direct and indirect storage technologies (e.g. electric vehicles), are under development, which also have the potential to dramatically change the system and enable an increased hosting capacity for renewable energy sources of the system.

B. Market and Regulatory Framework

At the same time that these changes to the physical system structure are taking place, the market and regulatory frameworks are under development. Numerous EU directives have laid the foundations for a liberalised electricity supply industry across European Union member states. The ongoing initiative is promoting a structure based on competitive, accessible market places to procure and sell system services and contracts for energy. To date, the principles of competition and market access have been focused on operation at the transmission level with small numbers of large generators, but this approach has yet to be devolved to distribution level, where it can facilitate access for thousands, potentially millions, of smaller participants to a competitive market place, to offer energy and system services.

The focus in the EcoGrid EU demonstration project is to enable smaller units to participate in the market and contribute to the system operation. The EcoGrid EU project will demonstrate an efficient operation of a distribution power system with high penetration of many and variable distributed energy resources. However, these paradigm changes will only unfold the desired effects to a full extent, if the consumers / customers understand and accept this transformation and have the means to adapt their consumption behaviour accordingly. Therefore, active customer participation plays a key role when developing strategies for Smart Grids and smart metering implementation.

C. End User Involvement

From the point of view of the end-user, the EcoGrid EU concept is simple. The current price of electricity is always known, and the end-user can in principle at any time take actions according to the electricity price, such as turning off or on selected appliances. Since the price can potentially change every 5 minutes, it is expected to let automatic end-user “smart controllers” make the decision based on the end-user’s more static preferences, and subsequently control the DER units and/or smart appliances. In addition to this, the end-user can receive relevant information about the electricity production, consumption, and prices, which brings a whole new dimension
into the user experience, in terms of energy awareness and commitment. End-user acceptance is crucial for deployment of the Smart Grids. In general people do not know about the electricity market and careful considerations must be made regarding end-user communication and involvement.

D. Smart Grid Retailers

Customer expectations and preferences, and the capabilities to respond to different prices are key research elements driven by the demonstration needs. The end-user must sign up for a contract with the supplier that in turn handles the final settlement and the financial obligations and risks towards the markets. Only end-users that have signed up for a real-time market contract are subject to the real time price. In other words, end-users who prefer other retail pricing systems are free to make any other contract with a retailer of their own choice.

As with the present wholesale markets, competition between retailers will lead to a variety of different contract types, and competition on the retailer’s cost for this service. The development of different contract types and associated business models will therefore be part of development of the EcoGrid EU concept.

The concept introduces price-based control of DER units, and thereby extends the time-scale limit of market-based solutions towards real-time, where until now only contract-based solutions have prevailed.

E. Information and Education of Consumers

The unique test site in Bornholm (see Figure 46) wants to take an active part in developing a Smart Grid energy system based on the EcoGrid EU concept and optimise the integration of renewable energy. Vital for realisation of the Smart Grid vision will be the energy management services and clean vehicle transport solutions. In parallel with the four year EcoGrid EU demonstration project, Energinet.dk has given support to the national ForskEL project known as “Information and Education of Future Electricity Consumers”. The project will develop a range of information, advice and training activities for consumers. The ForskEL project will establish a youth education programme on Smart Grid topics at Bornholm’s local gymnasium and schools. Through these education programmes, the students will have the opportunity to work with and understand the drivers behind Smart Grids and the impact on, for example, electricity consumption.

The project will also consist of organised activities aimed at training professional groups, such as electricians, artisans, carpenters and plumbers. The electrician should for example, have more expertise in management systems for homes and smart appliances that can be remotely controlled. The plumber who installs heat pumps must have similar knowledge about the possibility of remote and flexible operation of pumps. The carpenter must understand the concept of flexible consumption because housing is of great importance in determining electricity prices.

Many of the City customers expressing an early interest in the experiment assumed that this was an energy conservation project and had some difficulty making the connection to load management. It is also important that participants understand the whole concept therefore the success of EcoGrid EU is hinged on managing recruitment carefully from the initial phase of project. As a minimum, the test subjects should understand the function and the principle of load management and flexible consumption.
4.1.3. Analysis and Recommendations for Applicability to Thailand

A. Strong Renewable Energy Generation Mix

Thailand has embraced alternative energies such as hydropower and solar power projects up in the northern Thailand/Burma border and over 3GW of solar power has been proposed to the Thai national electricity authorities under the concessional power tariff. This is equivalent to approximately 10% of Thailand's current installed national power generation capacity. In addition, wind is also now in the mix. Siemens Energy won an order for 90 wind turbines to be installed at two plants in the north eastern part of Thailand that will provide a combined capacity of 200 megawatts eventually. A growing mix of renewable energy is also taking place in Thailand and the EcoGrid EU model is very much applicable to Thailand.

B. Accelerate PEA Smart Grid Project Roadmap Implementation

The PEA of Thailand is investing Bt400 billion (approximately US$13 billion) in the development of a nationwide Smart Grid over the next 15 years. A detailed Smart Grid Project roadmap was designed to integrate solar, wind power and supporting plug-in EVs. The Authority will pilot the Smart Grid technology in high power-consuming areas such as tourist destinations, including Phuket, Chiang Mai and Pattaya. The roadmap concluded by saying that no Smart Grid Cost-Benefit Model exists at the moment of writing, the very reason that the roadmap is very
conservative.\textsuperscript{55} The EcoGrid EU model will fill in the deficiency and provide Thailand with a proven model and also accelerate PEA's Smart Grid implementation, which has a potential to become the trendsetter for the rest of Asia. The tourist destinations are ideal sites for the project and capable of duplicating the EcoGrid EU site of Bornholm, Denmark.

C. Distribution Energy Resources (Electric Vehicle/Battery Supply)

Thailand is the 12th largest automotive manufacturing country in the world, building 1.6 million vehicles in 2010 and exporting 55% of them. The country is now trying to encourage foreign automakers to build cleaner, more efficient vehicles there. Thailand has to import a lot of oil, so it knows why small and fuel-efficient vehicles are important. The green vehicle program was the Board of Investment's Eco-Car Promotion. The total “eco car” production capacity is 585,000 vehicles per year, and the plan is to increase this export to more than 400,000 units per year. These car companies will also soon start producing electric cars in Thailand. In fact, there is one local company\textsuperscript{56} that has already converted the popular “tuktuk” into an electric vehicle.

However, even though Thailand is the centre for automobile production in the Southeast Asian region, the country still lacks a production base for EV batteries. The Board of Investment is coming up with a policy to encourage Japanese EV battery makers to set up production base in Thailand.\textsuperscript{57} When a significant volume of EVs are running in the streets, then Thailand will be increasing its DER which are flexible loads that are vital elements for the success of any Smart Grid concept. Existing storage equipment for end users will have to be improved and new ones developed to provide the balancing between supply and demand.

D. New Market and Regulatory Framework

With the Bornholm experiment, Thailand’s ERC can participate in the replication by giving special tariff scheme and special market framework for the participants to determine actual economic benefits and customer response. The challenge will be the acquisition of expensive ICTs and smart meters. Presently, Thailand has no spot market or retail market and the flexible tariff is only peak/off-peak rates for TOD/TOU applicable to medium-scale and large-scale customers. There are no options for residential customers. A new Smart Grid retail sector will have to be formulated together with the retail and probably wholesale spot electricity market to bring all electricity consumers to the Smart Grid concept and benefit.

E. Consumer Information Drive and Education

Thailand as a matter of policy can already implement consumer information drive and education via the tri-media and schools. Trainings of all stakeholders as exemplified by EcoGrid EU model can also be initiated.

\textsuperscript{55} http://analysis.smartgridupdate.com

\textsuperscript{56} Clean Fuel Energy Enterprise (CFEE) website (http://www.c-fee.com/)

\textsuperscript{57} Nation Multi Media website (http://www.nationmultimedia.com/business/BOI-wooing-Japanese-battery-makers-for-electric-ca-30178479.html)
4.2. GERMANY’S MEREGIO PROJECT

The German energy market is currently characterised by the increasing supply of renewable energy both from large onshore and offshore wind farms and through widespread local generation of solar energy. Legislation in the form of the ‘Erneuerbare Energien Gesetz (EEG)’ provides substantial subsidies toward renewable energy and therefore there is a great deal of supply, particularly of domestic PV and wind generation. Among the other challenges that accompany distributed generation, the key challenge for network operators is to keep the grid in balance. The transmission and distribution grids have been built to transport electricity generated at large power plants, which are mainly located close to the point of consumption. This is less complex than distributed generation systems, which are located further away.

Germany has fully approved its new energy policy and move the Smart Grid forward through their Grid Expansion Acceleration Act. The new law mandates the immediate shutdown of eight German nuclear power plants. It also includes a roadmap for the complete phase out of nuclear power by 2020.

Four German transmission system operators, responsible for balancing energy production and consumption, as well as maintaining power reserves have submitted to regulators three scenarios (see Table 12) for upgrading that nation’s power grid. These scenarios envision a future energy mix for Germany - which includes renewables, conventional generation, and smart energy demand.

**Table 12: Germany Energy Statistics**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Base 2010</th>
<th>Scenario A</th>
<th>Scenario B</th>
<th>Scenario C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>20.3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Brown coal</td>
<td>21.2</td>
<td>20.4</td>
<td>15.8</td>
<td>17.7</td>
</tr>
<tr>
<td>Black coal</td>
<td>29.5</td>
<td>33.4</td>
<td>26.2</td>
<td>21.9</td>
</tr>
<tr>
<td>Natural gas</td>
<td>22.1</td>
<td>23.3</td>
<td>37.0</td>
<td>23.3</td>
</tr>
<tr>
<td>Pumped storage</td>
<td>6.7</td>
<td>9.1</td>
<td>9.1</td>
<td>9.1</td>
</tr>
<tr>
<td>Oil</td>
<td>3.3</td>
<td>2.1</td>
<td>0.6</td>
<td>2.1</td>
</tr>
<tr>
<td>Other</td>
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<td>4.0</td>
<td>8.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Total, Conventional</td>
<td>106.1</td>
<td>92.3</td>
<td>98.8</td>
<td>92.4</td>
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<tr>
<td>Hydro</td>
<td>4.5</td>
<td>5.6</td>
<td>4.7</td>
<td>4.6</td>
</tr>
<tr>
<td>Onshore wind</td>
<td>27.0</td>
<td>33.4</td>
<td>44.0</td>
<td>61.0</td>
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<tr>
<td>Offshore wind</td>
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<td>11.3</td>
<td>13.0</td>
<td>28.0</td>
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<tr>
<td>Photovoltaic</td>
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<tr>
<td>Biomass</td>
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<td>7.4</td>
<td>9.1</td>
<td>10.0</td>
</tr>
<tr>
<td>Other</td>
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<td>1.8</td>
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<tr>
<td>Total, Renewable</td>
<td>55.0</td>
<td>93.5</td>
<td>126.6</td>
<td>171.7</td>
</tr>
<tr>
<td>Total Production</td>
<td>161 GW</td>
<td>186 GW</td>
<td>225 GW</td>
<td>264 GW</td>
</tr>
</tbody>
</table>

(Source: http://www.emeter.com)

56 http://smartgridsherpa.com/region/europe/germany
The scenarios presented in Table 12 may be described as follows:

**Scenario A**: All of the German government’s priorities for climate and energy policy will be implemented. This scenario expects a moderate rise in coal-fired energy production.

**Scenario B**: In addition to Scenario A, this scenario expects a larger portion of renewable power, as well as more natural gas-fired energy production. This would make the system more flexible and reliable, due to a diversified mix of energy sources.

**Scenario C**: This is the least realistic scenario. It is based upon a fictional assumption that Germany will have explosive growth in renewable energy, nearly tripling such resources between 2010 and 2022. It also does not expect that Germany will continue to build new fossil fuel-fired power plants through 2022.

It is with this energy backdrop in Germany that MeRegio was declared one of the prizewinners under the “E-Energy Project: ICT-based Energy System of the Future”, a new support and funding priority undertaken by the Federal Ministry of Economics and Technology (BMWi) as part of the technology policy of the Federal Government. Due to its utmost importance both in terms of innovation and the national economy, it was declared a beacon project at the National IT Summit of the Federal Chancellor.

### 4.2.1. Partnerships Behind the MeRegio Project

MeRegio, which means “Minimum Emission Region,” is focused on the development of a minimum emission certificate for the model region Karlsruhe/Stuttgart in Germany. It is a project by a consortium of six (6) partners composed of ABB, IBM, SAP, EnBW, Systemplan and the University of Karlsruhe. MeRegio is also supported by seven (7) development partners namely, BSH Bosch und Siemens Hausgeräte GmbH, Hoppecke / SMA, JOONIOR, Liebherr, Meteomedia, SenerTec and Vaillant. The aim of the certification is the complete elimination of CO2 emissions caused by heating and electrical power consumption. The data gathered is intended to motivate other regions to actively reduce their GHG emissions and promote specific measures to cut CO2 production.

The specific roles of the members of the consortium and the development partners for MeRegio are briefly described as follows:

**A. Main Partners (Consortium)**

Each partner is contributing its very specialist know-how and valuable experience for MeRegio to be a complete success. The spectrum spans from a technical infrastructure, special IT architecture to network management systems and simulations to customer care.

(1) EnBW Energie Baden-Württemberg AG - provide private and commercial test customers in the model regions with the technical infrastructure, e.g. the Intelligente Stromzähler (smart electricity meter), a dynamic tariff, the EnBW Cockpit.

(2) IBM Deutschland GmbH - responsible for the integral integration of IT systems and for realising the related business processes. With the E-Energy-Core Platform IBM is developing an architecture based on open mass data-capable and secure infrastructure which can thus react flexibly to new ever-changing business requirements.
(3) ABB AG - develop the network management system for MeRegio and is responsible for installing automated solutions in selected local network stations. The main aim of these activities is optimal use of the existing network infrastructure and optimal incorporation of the data from the Intelligente Stromzähler (smart electricity meter) into business management concepts.

(4) SAP AG is the global research organisation and a prototypical platform for the energy market of the future. Consumers will be able to choose between various energy sources, CO\textsubscript{2} emission rates and tariffs. Via the platform providers are to be granted simplified access to the market so that they can offer services through direct interaction with their customers in line with market requirements.

(5) Systemplan GmbH is committed to advising commercial and industrial customers in connection with the MeRegio project. The aim is to improve energy-efficiency and transparency of energy consumption in commercial and industrial companies and public institutions.

(6) The Karlsruher Institut für Technologie (KIT) is responsible for the scientific accompaniment and the development of a certificate for the Minimum Emission Region. This certificate is to be used to draw attention to the success in reducing the CO\textsubscript{2} emissions.

**B. Development Partners**

The development partners supporting the MeRigio Project in various capacities are briefly described as:

(1) BSH Bosch und Siemens Hausgeräte GmbH - developed smart washing machines that react to dynamic signals.

(2) Hoppecke/SMA - developed a battery system with customised power inverters which will be used for storing excess energy in order to increase the internal consumption rate at the household level.

(3) MSR office / Diehl Ako (JOONIOR) - developed an energy management system JOONIOR, intended to assist customers to automatically control selected end appliances.

(4) Liebherr - developed a smart upright freezer which can respond automatically to the dynamic signals. Since July 2011, the Liebherr product range has included eight Smart Grid-ready No Frost upright freezers.

(5) Meteomedia Energy - developed “Meteomedia signal algorithm” for the optimal forecast of decentralised producers, using weather data.

(6) SenerTec - developed interfaces to integrate the Dachs-micro-cogeneration system into the MeRegio Smart Grid, being the Europe-wide market leader for combined heat and power systems.

(7) Vaillant - developed an innovative micro-CHP systems.
4.2.2. Overview of the MeRegio Project

The MeRegio system aims to use energy intelligently, increase energy-efficiency and reduce CO₂ emissions (see Figure 47). The permanent exchange of data guarantees that electricity is always produced, fed and used as required (“energy on demand”). In particular, regional differences in electricity prices can be taken account for the first time. Power stations and decentralised production plants will operate at optimum capacity which will lead to a reduction of expensive control energy used to compensate for peak periods.

For each household, a smart meter with bi-directional broadband communication interfaces delivers a high level of transparency. In the home, electronic appliances can communicate with the central system and are thus coupled to a dynamic tariff. They recognise the times when electricity is cheap. A washing machine can be set to automatically switch itself on when a certain kWh price is reached when programmed in advance. The excess electricity (e.g. from a photovoltaic solar power plant) can be stored directly in the home, e.g. in an electric vehicle or in a stationary storage device. The short transmission path for energy production means that losses are reduced and the networks are not as highly overloaded. Within the pilot project, these meters will be installed at 800 consumer sites, 100 generation units and 100 storages for electrical energy.

MeRegio intends to promote the development of renewable energy such as photovoltaic, biogas, wind and water power. This project targets reducing the basic load on a daily basis, removing peak loads and shifting energy consumption. In particular it means being energy-conscious. As a result, the energy produced is used intelligently and remains affordable.

Figure 47. The MeRegio System
(Source: The E-Energy Project MeRegio – Experiences on Initial Planning & Development)
A more efficient integration of yield-dependent energy resources in the power grid represents another main toehold for the reduction of CO₂ emissions. Therefore customers will receive price signals as motivation for energy consumption. Figure 48 shows the schematic diagram of the Smart Grid system of the MeRegio Project.

In northern Germany, this situation already regularly occurs in the 60 and 110 kilovolt grid. Since there are currently no measure and communication technologies available, it is the function of restrictive grid codes to avoid such bottlenecks in subordinate voltage levels. Within the MeRegio project, meters and communication infrastructure will be used to detect the state of the grid on the medium- and low-voltage level. If bottlenecks are detected, the systems automatically set price signals as prevention and – if necessary – power plants will be switched off.

As it will not be possible to change existing grid codes within the pilot project, bottlenecks in low- and medium-voltage level will not occur in reality. Therefore, MeRegio will also simulate load flows in a virtual network model. This online-simulation will be used to analyse how the use of CO₂-free energy resources could be maximised in a market-oriented way if grid codes would change.

Another approach to cut CO₂ emissions in MeRegio involves the increase of network capacity and the reduction of network losses by introducing a marketplace for ancillary services. This marketplace will offer the possibility to trade products like reactive power. Such a marketplace, based on a network model, allows the efficient use of the existing envelopes of generation units to avoid voltage overshoots and to minimise network losses.

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**Figure 48. Schematic Depiction of MeRegio**
(Source: The E-Energy Project MeRegio – Experiences on Initial Planning & Development)
4.2.3. Phases of the MeRegio Smart Grid Project

The MeRegio Project Plan is divided into four functional phases namely; Measuring, Controlling, Storing and Trading (see Figure 49).

A. Project Phase 1: Measuring

The aim of the project is a marketplace for energy which connects the 1,000 private and commercial energy customers and centralised and decentralised energy providers. In Phase 1, anyone who tests the “network of the future” will be offered special technical equipment and a dynamic tariff.

The EnBW Intelligente Stromzähler ® (smart electricity meter) is the core of MeRegio. Via a broadband internet connection, data is sent to the server of the energy provider, Energie Baden-Württemberg AG (EnBW) and analysed in a graph form. From EnBW StromRadar© (energy radar), energy consumption is shown on a second-by-second basis on the computer screen. Consumers keep track of personal consumption and can immediately detect sneaky power-hungry appliances.

![Figure 49. Project Plan MeRegio](http://www.meregio.de/en/index.php?page=solution)

Transparency is the main principle of MeRegio. In purchasing or selling electricity, consumers can see exactly what the cost is at a specific time. If the customers are flexible in their personal consumption behaviour they can purchase particularly cheap energy. If, for example, the region is currently exposed to lots of sun and wind, a lot of energy from renewable energy sources will be available. At the same time large power plants will have produced energy nationwide according to schedule. Supply now exceeds demand and they can purchase the energy in their region at a lower price.
MeRegio means competitive advantages for commerce, industry and local authorities

This project offers, in particular, many attractive advantages for industrial and commercial customers and local authorities because this is where the saving potential is the greatest. Anyone who tightens the screw of energy-efficiency in his company, is forcefully pushing the cost brake. And this is quite simple by Smart Grids.

It all starts with what is known as the “Power Submeter” from Systemplan. With this innovative measuring instrument MeRegio gives customers transparency with respect to energy consumption in every plant area. On the basis of a 6-week measurement with the Power Submeter the consumption of consumers based on energy-use-areas is then analysed in detail.

B. Project Phase 2: Controlling

In Phase 2, customers are provided with the EnBW StromAmpel® (energy traffic light) so that they can use the individual tariff zones. In addition a few customers will also receive a control box which receives the weather-dependent price signal. This makes the Intelligente Stromzähler (smart electricity meter) even smarter because the control box can be programmed and can directly control individual electronic appliances in the home.

The appliance manufacturer Liebherr is also participating in the project. It provided freezers in order to put the intelligence of meter and control box through their control system. From the price signal and the appliance data it calculates the CO\textsubscript{2} efficiency optimum for each individual appliance.

C. Project Phase 3: Storing

In Phase 3, new smart appliances will be integrated into the MeRegio Smart Grid. In addition to the freezers from phase 2, dishwashers, e-storage heaters, heat pumps, stationary battery systems and in the context of the related project MeRegio Mobil, even electronic vehicles will be introduced.

Stationary battery system will be installed in the homes. It has a storage capacity of up to 20 kWh. For those who have a photovoltaic plant with a payment provision for saving excess energy, this battery is worth its weight in gold – it gives customers the opportunity to increase the consumption of the energy which they themselves have produced.

An energy management system will assist customers to gain even more control of their energy consumption. They will be able to measure the consumption of individual appliances. Furthermore, selected appliances will be controlled by a smart plug as part of the e-management system. If energy is cheap at a particular time, the system recognises this and all smart plugs switch on the corresponding appliances.

D. Project Phase 4: Trading

After adding appliances in Phase 3, the customers will then be given the opportunity to actively communicate with their energy supplier thus contributing towards optimising energy supply in Phase 4.
With the aid of an internet application, customers will be able to view the prognosis for their own consumption and will be able to notify the supplier of events which greatly influence consumption. In this way all consumers will be able to contribute towards improving the consumption prognoses. The decentralised production plant will have a storage unit that can decide when he feeds energy into the network and contribute towards taking some of the strain off the public network.

4.2.4. Project Outcomes and Applicability to Thailand

Initial results of the MeRegio Smart Grid implementation demonstrated that in Phase 1, the main test setup focused on the elasticity of consumers regarding dynamic pricing. The dynamic tariff has three price levels varying during the day, which was announced on the day-ahead. Consumers showed significant reactions to the changing tariff. There was an increase of energy efficiency and reduction of consumption by 1.7%. The load curves were compared to a reference group of 305 customers who already had a smart meter. Their characteristics were similar to the MeRegio customer.

Consumers reacted strongly by reducing their consumption at higher rates during the peak hours. The consumer reaction to use more at lower rates during the off-peak is relatively mild. More helpful information will be revealed when the MeRegio Project is completed.

MeRegio has an innovative and creative approach of using the concept of Smart Grid in mitigating carbon emissions. This kind of holistic approach in promoting and getting funds for acceleration of Smart Grid projects is very applicable for Thailand.

Like most EU Smart Grid projects, MeRegio is a consortium of established industry players that makes the project likely to succeed. The presence of an academe adds value to the consortium and provides the balance between profit, technological advancement and vision. Development partners also provide the necessary support in case needed adjustments are made in the middle of the implementation phase.

A consortium of local and international industry players will also be needed for the Thailand Smart Grid to proceed. The consortium concept must be very applicable to the PEA who is investing Bt400 billion in the development of a nationwide smart grid over the next 15 years. PEA needs plenty of help from other industry players for its PEA Smart Grid Road Map to succeed. PEA indicated partnership with E-Transport (or Electric Vehicles/EVs) that will provide the needed flexible load/DER. PEA will also contract service providers and consultants.

The four-phase ladderised project plan is also a good approach in the implementation of a full scale demonstration project since improvements can be done one step at a time. PEA's roadmap is also in four phases but covers a 20-year period. The conservative route is best explained by the concluding statement of PEA roadmap saying that no Smart Grid Cost-Benefit Model exists at the moment of writing.
4.3. FRANCE’S LINKY SMART METER PILOT PROJECT

The technological evolution of the French metering system is not unique since a 2009 European directive specified that in order to promote competition and energy savings, 80% of electricity meters should be smart by 2020.

A standard kWh meter measures only the accumulated energy consumption at a regulated fixed price. It cannot measure consumption on an hourly basis or respond to varying tariffs offered by suppliers in a spot market. In order to adapt to the changing electricity market regulations in Europe, France’s Commission for Energy Regulation requested the Électricité Réseau Distribution France (ERDF) to implement a pilot project on Smart Grid through installation of smart meters around France. ERDF is a subsidiary of Électricité de France S.A. (EDF; Electricity of France) EDF group, a leading European operator in the energy industry.

4.3.1. Background of the LINKY Smart Meter Pilot Project

ERDF chose the “LINKY” smart meter for its pilot project. Back in October 22, 2009, LINKY was awarded the Star of the Observeur design by the City of Science and Industry in Paris, which annually recognises the best achievements on collaborative works between companies and designers. The LINKY Smart Meter Project (see Figure 50) was designed to respond to three major challenges:

- Determine the installation process in installing huge amount of smart meters;
- Construct and commission the entire ICT system; and
- Confirm the economic assumptions of the project.

The project was officially launched in March 2010 in Greater Lyon and the Department of Indreet-Loire and was completed last March 31, 2011. Figure 51 presents a diagram of the LINKY infrastructure and the grid management opportunities it offers. ERDF deployed nearly 300,000 meters to test the viability of installing smart meters on the national level. In late 2011, the French government gave approval for 35,000,000 LINKY meters to be installed starting in 2013 after the successful one-year trial.\(^{60}\)

Figure 50. The LINKY System
(Source: Smart Grid and Linky Project, ERDF)

Figure 51. The LINKY Infrastructure and Grid Management Opportunities
(Source: Smart Grid and Linky Project, ERDF)
During the “Smart Metering UK & Europe Summit” in London last January 2012, LINKY received the “Roll Out Innovation Award” for the quality of its deployment system. Since the project began, about thirty foreign delegations from around the world were received by ERDF for LINKY presentation.

The LINKY Smart Meter project aims to test and demonstrate the actual field performance of smart meter based on automation, communication, scalability and reliability. Specifically, the objectives of the project were:

- Install 300,000 smart meters within one year;
- Improve meter functionality in a competitive electricity market environment;
- Improve customer satisfaction;
- Enhance distributor performance;
- Develop solutions to energy demand management and reduce CO$_2$ emissions; and
- Establish an industry standard for smart meters based on the following parameters:
  - Reliable and sustainable Information and Communication Technology
  - Benefit for the duration of the project from the technological advances
  - Open architecture and scalable.

Pilot project LINKY took the services of a consortium led by Atos Origin Integration and three equipment manufacturers namely; Landis & Gyr, Itron and Iskraemeco. By utilising these local companies for the design, manufacture, installation and testing of smart meters, the project boosted the local economy and contributed to national employment opportunities.

There were 350 people hired for the installation. In Lyon, five companies were hired (SPIE, Forclum Conjonxion, SLTP and Energy30) and more than 200 technicians were recruited and trained to install LINKY meters. In Indre-et-Loire, five companies were retained (ITO, Forenergies, Atlan’tech, and WindPhot Energy30) and 122 technicians were hired and trained.

To allay the common data security concerns of participating customers, the ERDF guaranteed the protection of personal information. Data encryption protected the system from malicious attacks that could harm the quality of service or compromise the customer’s privacy. From a regulatory perspective, the data belonged to the client and cannot be disclosed to third parties (e.g. supplier electricity) without the customer’s approval. ERDF assumed full responsibility in protecting the personal data of customers.

4.3.2. Key Results, Success Factors and Applicability to Thailand

The key performance indicators of the LINKY pilot project are as follows:

- 250,000 meters installed from March 2010 to March 2011
- 4,600 concentrators installed in the same period
- 30 minutes average installation of LINKY meter as per objective
- 1,500 meters average per day meter installation (with a peak in 2000 August 2010)
- Less than 1% complaints received regarding the installation
- 98% success rate on remote operations performed by the suppliers
- 95% success rate on two way communication
- Up to 170,000 increase in daily load curves
- The initial budget of 150 Million Euros has been met
The average outage time went down to 60 minutes per customer/year. In the early 1980s, the average outage time in France was about 400 minutes per customer per year. The connections between the meters, concentrators and the Central Information system were successfully tested and equipment interoperability confirmed.

With automation made possible by the LINKY smart meter, an average of 35,000,000 km of travel was saved by agents of ERDF, which reduced GHG emissions by 8,000 tonnes of equivalent CO$_2$.

After the LINKY pilot project delivery, ERDF announced its success and claimed to be ready to implement the installation of 35,000,000 smart meters on a national level. On 18 July 2011 the Commission of Energy Regulation has officially announced a national implementation of smart meters saying “it would be particularly beneficial to consumers”. Ongoing plans are to deploy 7,000,000 meters between 2013 and 2014, with 28,000,000 more to follow between 2015 and 2018.61

Last 10 July 2012, ERDF launched a dozen partnership initiatives to promote development of the next generation of Smart Grid technology within the country's borders, and promote its technological prowess elsewhere. ERDC manager stated that collaborations are necessary because much of what is needed to bring a new era of Smart Grids falls beyond the usual scope of major utility companies. The effort, comprised of demonstration initiative, pure partnerships and cross-cutting actions have been developed with leading market players, together with universities, major corporations and even startups.

The success of LINKY smart meter pilot project gave ERDF the confidence to initiate and coordinate the GRID4EU project with 27 partners in 12 EU countries partly funded by EU. The goal of the GRID4EU project is to carry on demonstration pilots of Smart Grids solutions on a large-scale basis. The initiative will implement 6 demonstration projects in 6 EU countries (Italy, France, Germany, Sweden, Spain and Czech Republic), to be integrated into a single one. It proposes solutions that go beyond the existing limits for electricity networks through the large-scale integration of distributed generation, the improvement of energy efficiency, the enabling and integration of active demand and new electricity uses.

The French government’s full support of the project and the position of ERDF as the implementing body are considered critical in the success of the project. Électricité Réseau Distribution France (ERDF) is a subsidiary of Électricité de France S.A. (EDF; Electricity of France) EDF group, the 2nd largest electric utility company in the world, after German RWE. ERDF was also ably supported by meter manufacturing specialists; Landis & Gyr, Itron and Iskraemeco.

The French are quite enthusiastic in coming up with an industry standard for Smart Grid implementations especially in their metering design which was based on open architecture and can be retrofitted to other brands, models and technologies. The one-year installation and steady operation of 300,000 meters is impressive considering that smart meter is still an emerging technology and plenty of glitches cannot be anticipated and corrected immediately.

62 France’s largest electricity distributor all in for smart grid development
After achieving its goals, the LINKY project paved the way for the national implementation of LINKY to 35,000,000 consumers. With the benefits realised in the pilot project, the replacement of new meters will be at no cost to the customer. There is already an incentive to the utility to push through with the massive undertaking given the improvement in the system’s reliability and efficiency covered the cost of the smart meter.

Thailand’s energy sector structure is similar to that of France with EGAT, PEA and MEA controlling the industry. They can implement a similar LINKY pilot project in coordination and approval of ERC with the support of the Thai government since considerable benefits are already proven by the EU demonstration projects. The improvement in system efficiency and reliability should serve as enough incentive for its immediate implementation.
Automatic Meter Reading (AMR): The technology of automatically collecting energy-related consumption, diagnostic, and status data from meters and transferring that data to a central database for billing, troubleshooting, and analysing. This technology mainly saves utility providers the expense of traveling to each physical location to read a meter. Another advantage is that billing can be based on near real-time consumption rather than on estimates based on past or predicted consumption. This timely information coupled with analysis can help both utility providers and customers, better control on the use and production of electric energy, gas usage, or water consumption. AMR technologies include handheld, mobile and network technologies based on telephony platforms (wired and wireless), radio frequency (RF), or power line transmission.

Bi-direction Energy Flows: Bi-direction or two-way energy is the flow of electricity to and from the grid. Today’s grids are designed for one-way flow of electricity. If a local sub-network generates more power than it is consuming, the reverse flow can create safety and reliability issues. A Smart Grid will manage these bidirectional flows in order to avoid reliability problems. Bi-direction energy flows allow small-scale generators (distributed generation) such as photovoltaic panels on building roofs, fuel cells, charging to/from the batteries of electric cars, wind turbines, pumped hydroelectric power, and other sources to send electricity into the grid.

Data: This is the information flowing to and from the customer to control the equipment. The information is collected from the customer, analysed and a collective decision is made by the controlling technology to provide energy to customer at the market price. Data is required to perform automatic monitoring and switching on/off of appliances. This information must be secured and protected, as it is critical to the customer. As the information grows and is communicated to the utility, the data storage and gateways will need to be increased. While the AC power control standards suggest power line networking would be the primary means of communication among Smart Grid and home devices, the bits may not reach the home via Broadband over Power Lines (BPL) initially but by fixed wireless.

Demand Response Support: Demand response support allows generators and loads to interact in an automated fashion in real time, coordinating demand to flatten spikes. Eliminating the fraction of demand that occurs in these spikes eliminates the cost of adding reserve generators, cuts wear and tear thus extending the life of equipment, and allows users to cut their energy bills by telling low priority devices to use energy only when it is cheapest. Currently, power grid systems have varying degrees of communication within control systems. In general, information flows one way, from the users and the loads they control back to the utilities. The total amount of power demand by the users can have a very wide probability distribution, which requires spare generating plants in standby mode to respond to any change. This one-way flow of information is expensive; the last 10% of generating capacity may be required only 1% of the time, and brownouts and outages can be costly to consumers. Latency of the data flow is a major concern, with some early smart meter architectures allowing 24 hour-delays in receiving the data, preventing any possible reaction by either supplying or demanding devices.

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Demand Side Management (DSM): This is the method of controlling the down side use of electricity by utilising voltage and current meters to sense the grid dynamics by monitoring changes in frequency of the power supply. Once patterns are established, loads are diverted or turned off to avoid blackouts, for example turning off air conditioners during short-term spikes in electricity price. The overall effect is less redundancy in transmission and distribution lines, and greater utilisation of generators, leading to higher reliability.

Home Area Network (HAN) devices: A HAN device located in the home can be connected to a home network. The device may be a home appliance, consumer electronics device, sensor, actuator, user interface, or controller. Examples of such devices typically involved with energy management include thermostats, HVAC (heating, ventilation, and air-conditioning) equipment, displays, and major appliances (called “white goods” by the appliance industry). The home network may be wired or wireless. For real-time energy management applications, the home network is linked to a utility network, possibly via a residential gateway. These appliances are called “smart appliances.” Smart appliances can communicate via the HAN with other appliances, with a HAN controller, or with the utility, depending on the application. Smart appliances respond to rate data or control signals from the utility in one of the following ways:

- Shed load in a times of excessive load or emergency (the controller may tell the smart appliances to shut down and reschedule).
- Shed load to prevent grid damage (protect transformer from overloading).
- Turn on when price signals are low to decrease electricity bills.
- Give customers choices regarding congestion and rate to make conscious decisions on use of electricity.

Integrated Communications: Integrated communications will allow for real-time control, information and data exchange to optimise system reliability, asset utilisation, and security. Communication devices are not uniform because they have been developed in an incremental fashion and not fully integrated with the grid operations. In most cases, data is being collected via modem rather than direct network connection and analysed. However, the equipment is not in place to control the devices at the customer’s location.

Load/Load Adjustment: The total amount of electricity used by customers at any given time is the load, thus, the total load for the grid changes based on usage. The grid provides electricity to the customers based on past information. Load adjustment is the use of new generation to respond to an increase in power consumption. A Smart Grid may warn all individual customers regarding load variance and to reduce the load temporarily or pay additional fees as deemed necessary. In the traditional grid, the failure rate can only be reduced at the cost of more standby generators.

Market Enabling: The Smart Grid allows for systematic communication between suppliers (their energy price) and consumers (their willingness-to-pay), and permits both the suppliers and the consumers to be more flexible and sophisticated in their operational strategies. Only the critical loads will need to pay the peak energy prices, and consumers can be more strategic when they use energy.

Generators with greater flexibility will be able to sell energy strategically for maximum profit, whereas inflexible generators such as base-load steam turbines and wind turbines will receive

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a varying tariff based on the level of demand and the status of the other generators currently operating. The overall effect is a signal that awards energy efficiency and energy consumption that is sensitive to the time-varying limitations of the supply.

At the domestic level, appliances with a degree of energy storage or thermal mass (such as refrigerators, heat banks, and heat pumps) will be well placed to ‘play’ the market and seek to minimise energy cost by adapting demand to the lower-cost energy support periods.

Peak Curtailment and Time of Use Pricing: This is a subset of DSM, meaning to reduce electricity during peak demand and highest prices. To reduce demand during the high cost peak usage periods, communications and metering technologies inform smart devices in the home and business when energy demand is high and track how much electricity is used and when it is used. This method gives utility companies the ability to reduce consumption by communicating to devices directly in order to prevent system overloads.

As a direct result of DSM, customers are motivated to utilise electricity when there is less demand on the grid and prices are low. As the market forces operate the grid, prices of electricity are increased during high demand periods, and decreased during low demand periods. It is thought that consumers and businesses will tend to consume less during high demand periods if it is possible for consumers and consumer devices to be aware of the high price premium for using electricity at peak periods. When businesses and consumers see a direct economic benefit of using energy at off-peak times, they become more energy efficient. The theory is that they will include energy cost of operation into their consumer device and building construction decisions.

**Power System Automation:** This enables rapid diagnosis of and precise solutions to specific grid disruptions or outages. Using SCADA and control systems to control substations, transformers, and meters, along with analytical tools (software algorithms and high-speed computers), the utilities are able to reduce outages and increase efficiency. In China, using artificial intelligence programming techniques, Fujian power grid created a wide area protection system that is rapidly able to accurately calculate a control strategy and execute it. The Voltage Stability Monitoring & Control (VSMC) software uses a sensitivity-based successive linear programming method to reliably determine the optimal control solution.

**Reliability:** This term is used for a grid that does not fail and is operational most of the time (98% or higher). The Smart Grid uses new technologies that improve fault detection and allow self-healing of the electric grid without the use of technicians. This will ensure more reliable supply of electricity, and reduced vulnerability to natural disasters or attack.

The existing grid also features multiple routes. Initially power lines were built radially and later connected via multiple lines, to create redundancy. This created a new problem, if current flow exceeded the line limits, the line would fail which could create a creating a domino effect. A method to prevent this is load shedding or voltage reduction (brownout). Smart Grid can prevent this by analysing load flows and redirecting current accordingly.

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**Sensing/Measurement Equipment:** Equipment such as advanced microprocessor meters (smart meter), wide-area monitoring systems, dynamic line rating, distributed temperature sensing, real time thermal rating, electromagnetic signature measurement/analysis, time-of-use and real-time pricing tools, advanced switches and cables, backscatter radio technology, and digital protective relays are all equipment used for evaluating congestion and grid stability, equipment health, and energy theft.

**Phasors Measurement Unit:** High-speed sensors called phasor measurement units (PMUs) are units to monitor power quality. Phasors are representations of the waveforms of alternating current, which ideally in real-time, are identical everywhere on the network and conform to the most desirable shape. In the 1980s, it was realised that the clock pulses from global positioning system (GPS) satellites could be used for very precise time measurements in the grid. With large numbers of PMUs and the ability to compare shapes from alternating current readings everywhere on the grid, research suggests that automated systems will be able to revolutionise the management of power systems by responding to system conditions in a rapid, dynamic fashion.

A wide-area monitoring system (WAMS) is a network of PMUs that can provide real-time monitoring on a regional and national scale. Many blackouts can be prevented because the problems in the Grid can be contained to a smaller area if a wide area phasor measurement network was in place.

**Smart Meter:** An electrical meter that records consumption of electric energy in intervals of an hour or less and sends information back to the utility for monitoring and billing purposes. Smart meters enable two-way communication between the meter and the central system. Unlike home energy monitors, smart meters can gather data for remote reporting. Such an advanced metering infrastructure (AMI) differs from traditional automatic meter reading (AMR) in that, it enables two-way communications with the meter and allows for a customer option.

**Smart Power Generation:** Smart power generation is a concept of matching electricity production with demand using multiple generators which can start, stop and operate efficiently at chosen load, independently of the others, making them suitable for base load and peaking power generation. Matching supply and demand, called load balancing, is essential for a stable and reliable supply of electricity. Short-term deviations in the balance lead to frequency variations and a prolonged mismatch results in blackouts. Operators of power transmission systems are charged with the balancing task, matching the power output of all the generators to the load of their electrical grid. The load-balancing task has become much more challenging as increasingly intermittent and variable generators such as wind turbines and solar cells are added to the grid, forcing other producers to adapt their output much more frequently than has been required in the past.

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72 Federal Energy Regulatory Commission Assessment of Demand Response & Advanced Metering

The first two dynamic grid stability power plants utilising the concept of smart power generation will be built by Wärtsilä in Kiisa, Estonia. Their purpose is to “provide dynamic generation capacity to meet sudden and unexpected drops in the electricity supply.” They are scheduled to be ready during 2013 and 2014, and their total output will be 250 MW.

**Sustainability:** As the grid develops, the grid will enable greater penetration of renewable energy sources such as solar, wind, biomass power. Existing grids are not designed to allow for many distributed feed-in points at the distribution level. In the future, the growth in distributed generation will allow for this. There are challenges to this sustainability, for example, cloudy or gusty weather, present significant challenges to the grid as there needs to be stable power levels through varying the output of the generators such as gas turbines and hydroelectric plants.

Smart Grid technology will enable the power engineers with tools to modulate for large amounts of renewable electricity on the grid. Next-generation transmission and distribution infrastructure will be better able to handle possible two-way flow into the grid.

**Wide Area Measurement System (WAMS):** The Bonneville Power Administration (BPA) developed sensors capable of rapid analysis of anomalies in electricity quality over very large geographic areas. The BPA System was operational in 2000. Other countries such as China, India, and Brazil are utilising this system and integrating it into the modern grids.

**Security:** There is also concern on the security of the Smart Grid infrastructure, primarily those involving communications technologies. Designed to allow real-time contact between utilities and meters in customers’ homes and businesses, there is a very real risk that these capabilities could be exploited for criminal or even terrorist actions. One of the key capabilities of this connectivity is the ability to remotely switch off power supplies, enabling utilities to quickly and easily cease or modify supplies to customers who default on payment. This is undoubtedly a massive boon for energy providers, but also raises some significant security issues. Cybercriminals have infiltrated the U.S. electric grid before on numerous occasions. Aside from computer infiltration, there are also concerns that computer malware like Stuxnet, which targeted SCADA systems that are widely used in industry, could be used to attack a Smart Grid network.
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• PEA's Effective use of information technology through its SCADA/DMS Power Point Presentation during the Renewable Energy World – Asia 2012 Conference, 5 October 2012 by Mr.PantongThinsatit
• Policy Statement of the Council of Ministers, delivered by Prime Minister Yingluck Shinawatra to the National Assembly on Tuesday 23 August 2011.
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• Renewable and Alternative Energy Development Plan for 25 Percent in 10 Years (AEDP 2012-2021)
• Smart Grids European Technology Platform for Electricity Networks of the Future
• Smart Metering Implementation Programme / Smart Metering Technical Equipment” prepared by Department of Energy and Climate Change. Draft provided to Parliament’s libraries dated September 2012. UK
• Thailand Smart Grid Development, EPPO
• World Economic Forum

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