ANNEX 15

Computer Simulation Modelling Report
EuropeAid/129506/L/ACT/TH
Thailand-EC Cooperation Facility – Phase II (TEC II)

GRANT CONTRACT
- EXTERNAL ACTIONS OF THE EUROPEAN UNION -
DCI-ASIE/2010/242-677

Smart/Intelligent Grid Development and Deployment in Thailand (Smart Thai)

COMPUTER SIMULATION MODELLING REPORT

Beneficiary/Applicant: World Alliance for Thai Decentralised Energy (WADE THAI), Thailand
Partner: World Alliance for Decentralised Energy (WADE), UK
Associate: Full Advantage Co., Ltd. (FA), Thailand

“Smart/Intelligent Grid Development and Deployment in Thailand (Smart Thai)” January 2013
10 January 2013

Director
World Alliance for THAI Decentralized Energy Association
(WADE THAI)

Re: Submitting the simulation model report as contract no. WT-2011-001

Dear Director WADE THAI,

According to contract no. WT-2011-001 signed on September 19, 2011; the WADE THAI as representative of World Alliance for Decentralized Energy in Thailand has signed a contract with Asian Institute of Technology (AIT) with an agreement that AIT shall conduct a simulation model research work for Thailand smart grid system based on WADE economic model.

Hereby, a report for that research work is attached to this letter as to submit as a result of the work by contract. The report is called “Initiative to WADE smart grid model” which contains 33 pages excluding cover divided into 4 chapters. Starting with a briefly definition of smart grid system and Thailand current situation, followed by model definition, design concept and methodology. The next chapter is stated how each scenario constructed, listing of assumptions and limitations. Finally, simulation results in various aspects as WADE concerned. A conclusion is also stated within the last chapter.

Sincerely yours,

W. Weerakorn Ongsakul, Ph.D.
Dean
School of Environment, Resources and Development
The WADE economic model is expected to contribute to decentralized energy but as of now the Smart Grid concept is growing around the world, an extension is developed. Based on WADE model an extension is constructed in parts with provided data from Thailand’s Provincial Electricity Authority (PEA) pilot project area.
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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>AMI</td>
<td>Advance Metering Infrastructure</td>
</tr>
<tr>
<td>BAU</td>
<td>Business as Usual</td>
</tr>
<tr>
<td>CCGT</td>
<td>Combined Cycle Gas Turbine</td>
</tr>
<tr>
<td>CG</td>
<td>Centralized Generation</td>
</tr>
<tr>
<td>CHP</td>
<td>Combine Heat and Power</td>
</tr>
<tr>
<td>CO2</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>DA</td>
<td>Distribution Automation</td>
</tr>
<tr>
<td>DE</td>
<td>Decentralized Energy</td>
</tr>
<tr>
<td>DEDE</td>
<td>Department of Alternative Energy Development and Efficiency</td>
</tr>
<tr>
<td>DG</td>
<td>Distributed Generation</td>
</tr>
<tr>
<td>DMS</td>
<td>Distribution Management System</td>
</tr>
<tr>
<td>DOE</td>
<td>Department of Energy</td>
</tr>
<tr>
<td>DR</td>
<td>Demand Response</td>
</tr>
<tr>
<td>DSM</td>
<td>Demand Side Management</td>
</tr>
<tr>
<td>EE</td>
<td>Energy Efficiency</td>
</tr>
<tr>
<td>EGAT</td>
<td>Electricity Generating Authority of Thailand</td>
</tr>
<tr>
<td>EMS</td>
<td>Energy Management System</td>
</tr>
<tr>
<td>EPPO</td>
<td>Energy Policy and Planning Office</td>
</tr>
<tr>
<td>ES</td>
<td>Energy Storage</td>
</tr>
<tr>
<td>ESMAP</td>
<td>Energy Sector Management Assistance Program</td>
</tr>
<tr>
<td>EV</td>
<td>Electric Vehicle</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>HEMS</td>
<td>Home Energy Management System</td>
</tr>
<tr>
<td>MDMS</td>
<td>Meter Data Management System</td>
</tr>
<tr>
<td>MEA</td>
<td>Metropolitan Electricity Authority</td>
</tr>
<tr>
<td>MSW</td>
<td>Municipal Solid Waste</td>
</tr>
<tr>
<td>NETL</td>
<td>National Energy Technology Laboratory</td>
</tr>
<tr>
<td>NOX</td>
<td>Nitrogen Oxide</td>
</tr>
<tr>
<td>NIST</td>
<td>National Institute of Standard and Technology</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>Operation and Maintenance</td>
</tr>
<tr>
<td>PDP</td>
<td>Power Development Plan</td>
</tr>
<tr>
<td>PEA</td>
<td>Provincial Electricity Authority</td>
</tr>
<tr>
<td>PMU</td>
<td>Phasor Measurement Unit</td>
</tr>
<tr>
<td>PM10</td>
<td>Particulate Matter</td>
</tr>
<tr>
<td>PTT</td>
<td>Petroleum Authority of Thailand</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>RE</td>
<td>Renewable Energy</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>SO2</td>
<td>Sulfur Dioxide</td>
</tr>
<tr>
<td>SPP</td>
<td>Small Power Producer</td>
</tr>
<tr>
<td>T&amp;D</td>
<td>Transmission and Distribution</td>
</tr>
<tr>
<td>USD</td>
<td>United States Dollar</td>
</tr>
<tr>
<td>USEPA</td>
<td>United States Environmental Protection Agency</td>
</tr>
<tr>
<td>VSPP</td>
<td>Very Small Power Producer</td>
</tr>
<tr>
<td>WADE</td>
<td>World Alliance Decentralized Energy</td>
</tr>
</tbody>
</table>
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List of Units

Kilo [k] $10^3$ Watt [W]
Mega [M] $10^6$ Megawatt [MW] $10^6$ Watt
Giga [G] $10^9$ Watt hour [Wh] 3.6 kJ
Tera [T] $10^{12}$ Joule [J]
Milli [m] $10^{-3}$ Kilojoule [kJ] 0.239 calories
Micro [μ] $10^{-6}$ Currency
Hour [h] 3600 sec 1 USD = 31.04 Thai Baht <As of May 2012>
Day [d] 24 h
Month [M] 720 h
Year [y] 8760 h
Executive Summary

As Smart Grid concept is being adopted worldwide, Thailand, through Provincial Electricity Authority (PEA) has initiated a roadmap strategy in the form of three concepts namely “Smart energy”, “Smart life” and “Smart community”. The development starts with the implementation of relevant technologies such as Advanced Metering Infrastructure (AMI), Distribution Automation (DA), Renewable Energy (RE), etc. The next step is to bring the different technologies to work in synergy to provide efficient and reliable source of power that will drastically improve the standard of living. Finally, Smart Grid is expected to provide an environmentally friendly community.

A pilot project for AMI implementation will be initiated through the deployment of 100,000 meters as announced by PEA in 2012 and will be one of the crucial steps for Smart Grid implementation in Thailand. This scope of this study will cover the area of Pattaya City which is the first pilot area for Smart Grid in Thailand.

In order to explore the Smart Grid benefits, a simulation model was developed anchored on the economic model from World Alliance for Decentralized Energy (WADE). It assumes that tariff schemes for different types of customers will be in placed such that rates are higher during peak period and lower during off peak. It is further assumed that customer demand response will be to lessen the use of power sourced from the grid during peak period when rates are higher and will instead shift their use during off peak when rates are lower. The model is structured into composites called “Load model”, “Feeder model”, “Feeder financial”, “Generation info”, “Generation finance”, “Emission calc”, and “Outcome”. Three different scenarios was used namely; Business As Usual (BAU), Peak reduction case (Case1) and Peak reduction with energy conservation (Case1+EC). The period covers the present up to 2030. The timeframe is divided into three phases to correspond with the gradual deployment of Smart Grid Technology until its full potential is realized. Three periods are defined as 2012-2017, 2018-2023, and 2024-2030.

Simulation results will show that by 2030, the demand will double based on the BAU case. Benefits can be clearly seen once the impact of Smart Grid implementation are considered and shown in the model. The peak demand will be reduced by two percent (2%) while the total cost will be reduced by seven percent (7%) in Case1. A seven percent (7%) reduction in demand and eighteen percent (18%) reduction in cost will be achieved for Case1+EC. While it is assumed that energy consumption is not changed even though peak is reduced, there are still some environmental benefits to the system. Volume of pollution emissions is reduced by about two percent (2%) and five percent (5%) on average for Case1 and Case1+EC respectively. While the benefit seems rather small, but in term of finance, the saving can be considerable compared to tariff collected. By the period of 2024-2030 the total investment cost is about 123 billion Baht while only 81 billion can be collected from existing tariff plan. Savings in terms of avoided cost is 7 billion and 20 billion with EC respectively.

(iv)
As a conclusion, this study is based only on the initial and limited deployment of Smart Grid technology based on the plans of PEA. Hence, only a small amount of benefit can be shown. However, as more advanced technologies are installed and corresponding policies are implemented, more benefits can be achieved for the community in the near future.
Chapter 1: Introduction to Smart Grid Technology

According to the US Department of Energy (DOE), there are six characteristics that comprises Smart Grid: [1]

1) Enables informed participation of customers;
2) Accommodates all generation and storage options;
3) Enables new products, services and markets;
4) Provides the power quality for the range of needs;
5) Optimizes asset utilization and operating efficiently;
6) Operates resiliently to disturbances, attacks, and natural disasters.

Furthermore, the interoperability and cyber security standard identified by NIST and DOE emphasize component, system-level and network-wide performance in each areas. The framework includes:

- That the framework be “flexible, uniform and technology neutral, including but not limited to technologies for managing Smart Grid information;”
- That it “accommodate traditional, centralized generation and transmission resources and consumer distributed resources;”
- That it be “flexible to incorporate regional and organizational differences; and technological innovations;”
- That it “consider the use of voluntary uniform standards for certain classes of mass-produced electric appliances and equipment for homes and business that enable customers, at their election and consistent with application State and Federal laws, and are manufactured with the ability to respond to electric grid emergencies and demand response signals;” and that “such voluntary standards should incorporate appropriate manufacturer lead time.”

To transform a “conventional” grid onto “smart” grid, investment must include a wide variety of technologies. The main investment capital would be in the upgrading of the information technology and grid sensor infrastructure. In order to efficiently operate the system and to serve the customers to meet those Smart Grid requirements, the availability of system status, information and management are required.

According to National Energy Technology Laboratory (NETL), key technology areas that comprise a Smart Grid are in five categories, namely: [2]

- **Advanced components**: Advanced components play an active role in determining the electrical behavior of the grid. They can be applied in either standalone applications or connected together to create complex systems such as microgrids. These components are based on fundamental research and development (R&D) gains in power electronics, superconductivity, materials, chemistry, and microelectronics
• **Advanced control methods**: Advanced Control Method technologies are "the devices and algorithms that will analyze, diagnose, and predict conditions in the modern grid and determine and take appropriate corrective actions to eliminate, mitigate, and prevent outages and power quality disturbances. These methods will provide control at the transmission, distribution, and consumer levels and will manage both real and reactive power across state boundaries."

• **Sensing and measurement**: Sensing and Measurement "is an essential component of a fully modern power grid. Advanced sensing and measurement technologies will acquire and transform data into information and enhance multiple aspects of power system management. These technologies will evaluate equipment health and the integrity of the grid. They will support frequent meter readings, eliminate billing estimations, and prevent energy theft. They will also help relieve congestion and reduce emissions by enabling consumer choice and demand response and by supporting new control strategies."

• **Improved interfaces and decision support**: Improved Interfaces and Decision Support are "essential technologies that must be implemented if grid operators and managers are to have the tools and training they will need to operate a modern grid. Improved Interface and Decision Support technologies will convert complex power-system data into information that can be understood by human operators at a glance. Animation, color contouring, virtual reality, and other data display techniques will prevent data overload and help operators identify, analyze, and act on emerging problems."

• **Integrated communications**: a foundational need, required by the other key technologies and essential to the modern power grid. Integrated communications will create a dynamic, interactive mega infrastructure for real-time information and power exchange, allowing users to interact with various intelligent electronic devices in an integrated system sensitive to the various speed requirements (including near real-time) of the interconnected applications.

In Thailand, PEA has started its Smart Grid project in 2010., The objectives of PEA’s roadmap are divided into three concepts namely; Smart Energy, Smart Life, and Smart Community. [3]

1) **Smart Energy** refers to the Smart Electrical Energy Supply/Source, Smart Electrical Power system/Delivery including:
   - Renewable Energy
   - Distributed Generation
   - Energy Storage
   - Electric Vehicle
   - Virtual Power Plant (VPP)

The main features of these concepts are:
   - System works automatically in normal and emergency conditions
Chapter 1: Introduction to Smart Grid Technology

- Provide better sensing and monitoring the real-time status
- Manage power consumption effectively
- Reduce peak load
- Add in electrical support for renewable energy sources
- Two-way communication with individual electrical appliances and applications
- Facilitate sale and purchase of electricity to the parties
- Support electric vehicle
- Support residential and office building automation

2) **Smart Life** means the ability to support daily lifestyle in the home and work. Power users can participate in the management of electricity supply. Power users have the option to manage energy use to match their lifestyle. PEA will promote the intelligent use of energy resources and provide tools for efficient use inside homes or offices. This will result in slower increase in electricity consumption nationwide. It can also slow down requirement for new power plants, thereby reducing greenhouse gas emission and global warming.

3) **Smart Community** denotes intelligent and green community or society with respect to energy usage and environmental friendly. PEA will provide infrastructure support to serve electric vehicles and private members of the community to produce electricity from renewable energy sources (grouped as virtual power plant).

Those three concepts can be depicted through five strategies as shown below:

<table>
<thead>
<tr>
<th>Smart Energy</th>
<th>Smart Community</th>
<th>Smart Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distributed Generation</td>
<td>Network</td>
<td>E-transport</td>
</tr>
<tr>
<td>- VSPP</td>
<td>- AMR/AMI</td>
<td>- Demand creation</td>
</tr>
<tr>
<td>- DG</td>
<td>- Reliability</td>
<td>- Real-time pricing</td>
</tr>
<tr>
<td>- RE</td>
<td>- Power quality</td>
<td>- Charging station</td>
</tr>
<tr>
<td>- Storage</td>
<td>- Energy</td>
<td>- Battery management</td>
</tr>
<tr>
<td></td>
<td>- Efficiency</td>
<td>- Financial management</td>
</tr>
<tr>
<td></td>
<td>- ICT integration</td>
<td>- Public awareness</td>
</tr>
<tr>
<td></td>
<td>- Asset utilization</td>
<td></td>
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</tbody>
</table>

From the strategies we can sort out the main technologies that needed to be installed into system in the old fashion G-T-D-C categories.
Table 1.2: Smart Grid system features

<table>
<thead>
<tr>
<th>Generation</th>
<th>Transmission</th>
<th>Distribution</th>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PMU, GIS, EMS, SPP, ES</td>
<td>PMU, GIS, DMS, DG, ES, DA</td>
<td>AMI, MDMS, DG*, HEMS, ES, EV, DR</td>
</tr>
</tbody>
</table>

**Generation sector**: Main entities are bulk power producers such as EGAT and IPPs. In technological point of view, not much change is needed in this sector but producers may opt for cleaner technology.

**Transmission sector**: Transmission system is entirely owned by EGAT while sub-transmission system ownership is owned by EGAT and PEA. Most improvements needed for this sector are real-time measurement of any components in the system which can be done through Phase-measurement-unit integrated with Geographical-information-system. To efficiently manage and balance the supply to demand, which are not only from generation sector but also small power producers and energy storages attached to the grid. Additionally, there shall be market mechanism taking place to promote more competitive and challenge on participants of the system.

**Distribution sector**: This is mainly owned by PEA. Due to vast coverage of PEA’s network, massive deployment of sensing and measuring units will be required to complement AMI. Moreover information obtained from those units will be used by the Distribution Management System (DMS) and Operation Management System which employs decentralized concept. The DMS has to ensure that all assets are efficiently and economically operated. DMS will not only implement distribution automation but conditional maintenance as well. Having direct contact to customers and bulk power through the transmission system, the distribution utilities must providemetering units with sophisticated functions such as net metering for increasing prosumers (consumer with production capability) and remote control for reverse power flow. Furthermore, market mechanism would allow participants to take full benefits of the scheme.

**Customer sector**: The infrastructure requirement will depend on the size of the customer load. Most customers are attached to low voltage level through the distribution transformers with varying service requirement such as residential, commercial buildings and others consumers. Altogether they constitute about half of the country’s electricity consumption with little active interaction with utilities. So new AMI infrastructure started by utilities will enable AMI customers to actively two-way communication with utilities, and enable more and better quality of power delivery services. The success of Smart Grid on the customer sector is dependent how interested people will employ AMI since it acts as gateway and data collector at customer location. It collects and transmits data to utilities’
operating center or data center for demand-side application and for further analysis. For the customers, AMI would enable them to manage their consumption, remotely control and schedule use of appliances through home or building energy management at a time when rates are at its lowest thereby reducing power cost while keeping a comfortable, convenient and environmentally friendly lifestyle. Customers with embedded generators can make use of AMI to get real time tariff information in order to optimize operational schedule of their devices.

**Summary**

The first step in moving towards Smart Grid is the installation of AMI such as data collectors and actuators that work automatically and coordinate all resources in the grid so that the power system can achieve a steady load with close to 100% load factor. The whole system will then be operating at the optimum with the most efficient use of resources and lowest carbon emission. Generation sector will have to utilize more green technologies, while transmission and distribution sector will have to install state of the art sensors and gadgets that will provide real time information and control on the remotest part of the grid. Within the distribution sector, distribution management system will be needed to be able to optimize assets and accommodate all distribution resources. It is in the customer sector that dramatic changes have to take place so that it can be more proactive and concerned in its energy usage. Therefore the customer sector response is the key factor that will enable the Smart Grid and keep it sustainable.
References


Chapter 2 WADE model and the initial extension to Smart Grid model

The WADE economic model was introduced by World Alliance for Decentralized Energy (WADE) to demonstrate the better performance of decentralized energy resource (DE) against centralized power generation (CG) in meeting future electricity demand growth. WADE model directly compares economic and environmental factors based on extensive input data and defined assumptions. [1]

The required input fields include:

1. existing generating capacity and power output by technology
2. pollutant emissions by technology type
3. heat production, fuel consumption and load factor by technology type
4. capital and investment costs of generating capacity and T&D
5. operation and maintenance (O&M) and fuel costs by technology type
6. estimates of overall and peak demand growth for the system
7. estimates of future capacity retirement by technology type in five-year steps
8. estimates of future proportion of capacity installed by technology type in five-year steps

Outputs that are calculated include:

1. relative retails costs
2. relative capital costs
3. relative emission of CO2 and other pollutants
4. relative consumption of fossil fuels

WADE claimed that the model provides a tool to enable policymakers and DE industry group to understand the economic and environmental benefits of DE. There are many countries all over the world that has adopted the WADE model and it is also expected that Thailand will also use the model for project of WADEThai.

The work described here and throughout the rest of the report is an extension of Thailand WADE model project which is an introduction to WADE Smart Grid modeling for Thailand. As described in Chapter-1, Smart Grid is composed of many components and to model such system is no easy task. One of the main features of Smart Grid is dynamic demand management which enables customers to examine their pattern of consumption and take advantage of different rates at different times. Hence, demand response (DR) is required and countries that started implementing Smart Grid leader spent huge investment in AMI system.

This model will be composed of the following:
1. **Load model**: a collection of different normalized load profiles of different types of load and the modified model that simulates load enhanced by Smart Grid system.
2. **Feeder model**: a combination of load models that show system demand and consumption on a daily, monthly and yearly basis.
3. **Feeder financial**: contains financial calculation relating to components of the Feeder model.
4. **Generation info**: is composed of matching calculations between load demand and consumption to generation capacity of various types of power plants.
5. **Generation finance**: contains financial calculation relating to components in generation info.
6. **Emission calc**: calculated quantity of emitted pollutants, four types are considered.
7. **Parameters**: predefined parameters used within model program.
8. **Outcome**: list of interesting results of the simulation model.

The main parts of the model from “Feeder model” to “Emission calc” are used to create cases. Each case result is listed in the “Outcome”. They are categorized into three groups:

1. Load and distribution level which includes load model, feeder model and feeder financial.
2. Generation and transmission level which includes generation info, generation finance and emission calc but within this simulation model most of transmission level information is neglected except for transmission losses and costs related to generation.
3. Result and parameter which includes the worksheets.

The details are being described in the following context in this report.

![Model Diagram](image)

**Figure 2.1 Model Diagram**

The input fields are those of WADE model and additional inputs for applying Smart Grid model are stated as followed. Each sheet required input is separately listed in table 2.1.
Table 2.1: Input data of the model

<table>
<thead>
<tr>
<th>Worksheet</th>
<th>Type of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load model</td>
<td>• Hourly normalized load profile of each load type (categorized by tariff plan)</td>
</tr>
<tr>
<td></td>
<td>• Average daily peak of each profile</td>
</tr>
<tr>
<td>Feeder model</td>
<td>• Combination of load per feeder</td>
</tr>
<tr>
<td></td>
<td>• Monthly distributed peak ratio</td>
</tr>
<tr>
<td></td>
<td>• Yearly distributed peak ratio</td>
</tr>
<tr>
<td></td>
<td>• Annualized demand and energy consumption growth</td>
</tr>
<tr>
<td></td>
<td>• Average distribution system losses</td>
</tr>
<tr>
<td></td>
<td>o Equipment losses</td>
</tr>
<tr>
<td></td>
<td>o Line losses</td>
</tr>
<tr>
<td></td>
<td>o Substation losses</td>
</tr>
<tr>
<td>Feeder financial</td>
<td>• Capital cost, Operation and maintenance cost per component</td>
</tr>
<tr>
<td>Generation info*</td>
<td>• Existing and future capacity of selected CG and DE technology according to WADE model</td>
</tr>
<tr>
<td></td>
<td>• Expected load factor of each generation technology</td>
</tr>
<tr>
<td></td>
<td>• Reserve margin percentage</td>
</tr>
<tr>
<td></td>
<td>• Average transmission system losses</td>
</tr>
<tr>
<td>Generation finance*</td>
<td>• Average capital cost, O&amp;M cost by technology of generation according to WADE model</td>
</tr>
<tr>
<td></td>
<td>• Average fuel cost</td>
</tr>
<tr>
<td></td>
<td>• Average transmission and distribution costs, financial term, return on capital by technology according to WADE model</td>
</tr>
<tr>
<td>Emission calc*</td>
<td>• Emission factor for NOx, SO2, PM10 and CO2 by technology of generation according to WADE model</td>
</tr>
<tr>
<td></td>
<td>• Heat rate by technology</td>
</tr>
</tbody>
</table>

Source: Author, 2012, based on WADE model

**Detail of mechanism inside “Load model”**

<Worksheet figure in appendix A>

This worksheet is constructed in order to serve as a basis for the whole model. The hourly load profile has been normalized and listed. Two separate profiles were used, one for working day (Monday – Friday) and another for weekends (Saturday, Sunday) in hourly basis. Twenty seven (27) types of load profile were produced based on data collected from Provincial Electricity Authority (PEA) [2, 3] of Thailand. Beside the base profiles, modified profiles were created after each load has applied smart system or Smart Grid has been implemented. Only peak shifting is taken into account for this simulation which means energy consumption remains the same. These modified profile models are collaborated with
the “Feeder model” sheet of a BAU case where the off-peak hours of the system are
determined.

“Feeder model” and “Feeder financial” calculations

Feeder model:

< Worksheet figure in appendix A >

From top to bottom loads are listed which modeled as total system quantity at the top then
breakdown into substations, feeders and loads. Each feeder may comprise of different
number of loads depending on “actual feeder profile” [3].

Each hour total demand is assessed by summing all load requirements from each modeled
feeder as shown in the formula

\[ \text{Demand}_h = \sum_{i} p_{hi} d_i n_i \]

Where \( p_{hi} \) is normalized profile at hour \( h \) of load \( i \), \( d_i \) is peak demand of load \( i \) and \( n_i \) is
amount of load \( i \) in a modeled feeder.

Daily energy requirement is computed as a sum of the demand for 24 hours. The peak is
also being considered. As for monthly energy consumption, both working days and
weekends in the combination of 20 and 10 days respectively were taken into account. The
number of days are computed as shown below:

\[
\text{Working days} = \frac{\text{Year} - (\text{Weekends} \times \text{no. weeks} + \text{official holidays}^4)}{\text{no. month}}
\]

\[
\text{Working days} = \frac{365 - (2 \times 52 + 16)}{12} \approx 20
\]

After a peak is calculated on a month basis, it is multiplied with the distribution factor to
generate a yearly peak demand. The same process goes to energy consumption which
numbers of days are utilized. This distribution factor is derived from EGAT annual report
2010 [5] and 2011 [6]. Forecast demand and energy consumption are computed as the
growth rate taken from Thailand Power Development Plan 2010 revision 3 (PDP2010ver3) [7].

\[
\text{MonthlyPeakdemand} = \max(\text{demand.weekday}, \text{demand.weekend}) \\
\times \text{monthly.demandfactor}
\]
Chapter 2: WADE model and the initial extension to Smart Grid model

Finally, the required capacity for feeder components is calculated based on the demand forecast. This is used to calculate capacity investment for feeder side cost calculation.

There is one additional process for a BAU case, which is to consider the off-peak (valley) hour of the system consequently that shifted peak cases could be moved to. By simply considering the total demand in hourly profile for one day span if that hour is lower than average or not. If it is then that hour is marked as valley hour. We both consider separately for working days and weekends.

*Feeder financial:*

< Worksheet figure in appendix A >

One may notice that this worksheet has been made in the same layout as feeder model. First, we calculate the capital and O&M costs for each utility’s component base on future required capacity calculated in “Feeder model” sheet. Then, it is due to the fact that it is the modified case or not, if it is investment and O&M cost for smart system is determined with data source from international experience [8]. The rest in this worksheet are tariff related calculations.

Demand charge and energy charge are separately listed in order to be easily compared later. All the tariff cost and peak period are based on PEA tariff rates [9].

*“Generation info”, “Generation finance” and “Emission calc”*

These worksheets have obtained information based on previous WADE model project from WADE Thai, either choosing of types of generation technology, calculation on base capacity or some other parameters.

*Generation info:*

< Worksheet figure in appendix A >

Aside from choosing generation technology to the model is to consider order for each type to serve demand. So, at first we determine priorities to each generation type according to price per unit production, then re-adjust priorities by environmental impact, all of these must be done while considering plant types whether it suits for base, intermediate or peak
Chapter 2: WADE model and the initial extension to Smart Grid model

demand. From Feeder model’s demand requirement at each time-span, it has been distributed onto each generation technology according to determined priority. Not a fully hundred percent is accounted for allocating the demand, the capacity factor is restricted such as solar PV system has a factor of no more than thirty percent due to availability of sunlight. For each hour each generator’s generation required capacity can be calculated as followed;

\[
Gen_{n,l} = \begin{cases} 
(D_h \times CP_{i}) & \text{if } l = 1, D_h < Gen_{l,\text{max}} \\
(D_h - \sum_{j=1}^{n} Gen_{h,j}) \times CP_{i} & \text{if } l \geq 2, D_h < Gen_{l,\text{max}} \\
Gen_{l,\text{max}} \times CP_{i} & \text{if } D_h \geq Gen_{l,\text{max}} 
\end{cases}
\]

Where \( D_h \) is total demand at hour \( h \), \( CP_{i} \) is capacity factor of priority \( i \) generator and \( Gen_{l,\text{max}} \) is maximum capacity of a generator. Then, for energy supply, it is determined regarding calculated generating capacity.

Generation finance:

To illustrate financial parameters for generation side of the system, capital cost, transmission and distribution costs, O&M cost, fuel cost, these are relevant values taking into account here. Most of them base on WADE model but for data source, it is available mainly Thailand data is applied.

Therefore only yearly forecast quantity is computed in this sheet based on required capacity calculated in Generation info. Finally, a price per unit is considered using formula;

\[
Price_{i,y} = Price_{i,y-1} + \left(\frac{\text{Capital investment}_{i,y}}{\text{total lifetime in hour}}\right) + \left(\frac{\text{O&M cost}_{i,y} + \text{Fuel cost}_{i,y}}{\text{total Kwh}_{i,y}}\right)
\]

Where index \( i \) indicates generator \( i \) and \( y \) indicates year, O&M cost, Fuel cost and total Kwh are only accounted for newly installed capacity in the year \( y \).

Emission calc:

As well as generation finance, emission factors are based on WADE model and only four major pollutants are considered. With this model, to assess environmental emission, first we need to calculate generating capacity required to serve the demand. As peak demand decreased due to smart system application, the peak serving power plant (peaking plant) is having less operation time. These peaking plants are normally high emission rate power
plant such as diesel engine power plant or diesel gas turbine. By shifting peak demand to valley period, the intermediate plant which normally less polluting is carrying those shifted load. So the amount of emission impact is decreased.

Figure2.2: peak shifting

In this simulation, to practically calculate we assign each generation with dispatching priority depending on production cost and emission factor e.g. lignite or coal power plant can be prior to renewable such as biomass or CHP due to lower cost and solar PV or wind turbine power plant can be prior to gas fired steam turbine due to lower emission. This priority order can be crucial factor to emission level.

To calculate each generation capacity for each type in each time period, formulas are shown;

\[
\text{Generating MW}_{p1} = \min \left( \text{demand}_{p1}, \max(\text{available capacity}_{p1}) \right)
\]

\[
\text{available capacity}_{p1} = \max(\text{capacity}_{p1} \times \text{capacity factor}_{p1})
\]

\[
\text{demand}_{p1} = \text{Total required demand}
\]

\[
\text{Generating MW}_{p2} = \min \left( \text{demand}_{p2}, \max(\text{available capacity}_{p2}) \right)
\]

\[
\text{available capacity}_{p2} = \max(\text{capacity}_{p2} \times \text{capacity factor}_{p2})
\]

\[
\text{demand}_{p2} = \text{Total required demand} - \text{Generating MW}_{p1}
\]

\[
\text{Generating MW}_{p3} = \min \left( \text{demand}_{p3}, \max(\text{available capacity}_{p3}) \right)
\]

\[
\text{available capacity}_{p3} = \max(\text{capacity}_{p3} \times \text{capacity factor}_{p3})
\]
While $P1, P2, P3$ are priority number

Or in general;

\[
demand_{P_t} = \text{Total required demand} - \sum_{n=1}^{2} \text{Generating MW}_{P_n}
\]

\[
\text{Generating MW}_{P_t} = \min \left( \text{demand}_{P_t}, \max(\text{available capacity}_{P_t}) \right)
\]

\[
\text{available capacity}_{P_t} = \max(\text{capacity}_{P_t}) \times \text{capacity factor}_{P_t}
\]

\[
demand_{P_t} = \text{Total required demand} - \sum_{n=1}^{t-1} \text{Generating MW}_{P_n}
\]

With peak supply available from above formulas, future peak supply is forecasted with forecasted demand each year collected from feeder model worksheet. Then each year energy supply is calculated using those forecasted peak supply. Finally pollutant emission is determined with energy supply per year and emission factors.

“Outcome”

< Worksheet figure in appendix A >

Interested results from simulation are listed; hence it can be compared case by case. The results are averaged onto three periods 2012-2017, 2018-2023 and 2024-2030 according to assumption that the smart system will need to be re-invested every period. Detail results from calculation are shown in chapter-4.
Chapter 2: WADE model and the initial extension to Smart Grid model

References:

[3] PEA load profile of AMRs and Substations in Pattaya area, <information from PEA staff>
[9] PEA tariff rates, June 2012
Chapter 3 Scenario development, Assumptions and Limitations

Cases design in general:

Cases are modeled in order to examine the effect of smart system while changing parameters. There are four cases initiated for this purpose, a BAU case and three peak-shifting cases for 5%, 10% and 15%. The percentage number for each scenario is based on potential of demand response in peak reducing from various studies [1-5].

Business as Usual (BAU) case:

Assuming no smart device has been installed within the system, each profile remains untouched and the future capacity of CG and DE is based on PDP2010 with existing of nuclear power plant.

Peak demand shifting cases:

Assuming each customer has equipped with smart devices which enables profile changing, a percentage of peak demand is cut and shift to the valley hours. These valley hours are determined from BAU case total demand profile where the demand is low. Each load may shift a maximum of percentage described by case but not more than 10% per hour is available to be filled as shown in figure.

![Figure 3.1 Peak reduction with valley filling](image)

Each case contains four worksheets, feeder model, feeder financial, generation info and generation finance. To configure cases simply choose the combination of load models and modified ones in the feeder model sheet. Then, the rest calculations shall be done in the same manner.

Aside from peak shifting cases, an energy conservation scenario is combined with normal cases to further investigate outcomes of the model and to cope with normal Smart Grid assumption of which energy conservation case is usually included. An average percentage reduction is applied to total demand profile.
Assumptions and limitations:

One may notice that in order to call a system “Smart Grid”, there must be various components operating in that system. According to PEA roadmap described in Chapter-1, at the first step of “Smart Energy”, there are several features required;

- System works automatically in normal and emergency conditions
- Provide better sensing and monitoring the real-time status
- Manage power consumption effectively
- Reduce peak load
- Add in electrical support for renewable energy sources
- Two-way communication with individual electrical appliances and applications
- Facilitate sale and purchase of electricity to the parties
- Support electric vehicle
- Support residential and office building automation

This simulation model is not able to represent all feature listed, however, assumptions and limitations have been made. As described in Chapter-2 and earlier this chapter, we only represent peak load reduction by peak shifting as load dynamic. Assumptions and limitations applied in each modeled worksheet and calculations are stated in below;

1) Load information is accounted for area of Pattaya Cityas following PEA pilot project [6].
2) Only peak shifting is considered as load dynamic to ease calculation and inspection of outcomes.
3) Electric vehicle is excluded from this simulation due to highly dynamic behavior.
4) A shifted profile shall consume the same amount of energy as normal one to emphasize on controlling ability of Smart Grid by peak shifting.
5) Home automation cost is not included; however communication backbone cost for AMI system is included [7].
6) Because it is difficult to state which generation site should be included serving the modeled area. As a result only a fraction from country generation capacity is applied to simulation, a scale factor is considered by calculation.

Data input as based on above descriptions is put into a designed model not only forecast the demand and generation requirements but also examine the environmental impact and financial cost. As mentioned above 3 cases with 2 scenarios, 3 cases of peak shifting with and without energy conservation are built by varying different peak reduction potential parameter of each single load. A base case is selected on a case of 5% reduction (Case1) to convey the most conventional approach. The selection is based on a least capacity that the
Chapter 3: Scenario development, Assumptions and Limitations

Smart Grid should achieve from various studies [1-5]. However, if one would prefers higher or lower setting it is possible to adjust as model is easily configurable.

**Reference scenario assembly in brief:**

Required inputs, as describe in Chapter-2, are gathered from various sources. Here we illustrate how it is assembled;

Again, as mentioned above load profiles are collected from PEA mainly two sources [8, 9]. Models have been formed from region-wide average and local-area load profiles according to PEA tariff classification are picked;

Table 3.1: picked load profile and peak demand

<table>
<thead>
<tr>
<th>Load profile</th>
<th>Model name</th>
<th>Peak demand [KW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Residence (&lt;150kwh/ month)</td>
<td>House_A</td>
<td>4.0</td>
</tr>
<tr>
<td>Average Residence (&gt;150kwh/ month)</td>
<td>House_B</td>
<td>7.0</td>
</tr>
<tr>
<td>Average Small general service</td>
<td>Small_C</td>
<td>29.0</td>
</tr>
<tr>
<td>Average Medium general service</td>
<td>Medium_D</td>
<td>500.0</td>
</tr>
<tr>
<td>Average Large general service</td>
<td>Large_E</td>
<td>1300.0</td>
</tr>
<tr>
<td>Average Government and non-profit</td>
<td>Gov_G</td>
<td>120.0</td>
</tr>
<tr>
<td>Average Specific business (Hotel)</td>
<td>Hotel_F</td>
<td>50.0</td>
</tr>
<tr>
<td>Local Grocery store</td>
<td>Grocery_P</td>
<td>16.8</td>
</tr>
<tr>
<td>Local Residence</td>
<td>House_P</td>
<td>39.1</td>
</tr>
<tr>
<td>Local Bank</td>
<td>Bank_P</td>
<td>62.9</td>
</tr>
<tr>
<td>Local Nightclub</td>
<td>Nightclub_P</td>
<td>138.7</td>
</tr>
<tr>
<td>Local School</td>
<td>School_P</td>
<td>149.7</td>
</tr>
<tr>
<td>Local Government office</td>
<td>Gov_P</td>
<td>361.8</td>
</tr>
<tr>
<td>Local Factory</td>
<td>Factory_P</td>
<td>515.6</td>
</tr>
<tr>
<td>Local Shopping mall</td>
<td>Mall_P</td>
<td>1668.8</td>
</tr>
<tr>
<td>Local Hotel</td>
<td>Hotel_P</td>
<td>1746.0</td>
</tr>
<tr>
<td>Local Hospital</td>
<td>Hospital_P</td>
<td>1796.8</td>
</tr>
</tbody>
</table>

To represent a feeder with this limit number of profile is almost impossible hence we generate more profiles of residential type to represent different behaviors. All generated profiles are based on author’s assumption on various household electric appliances used in Thailand.

Twenty seven load models have been made so far; these models are integrated to replicate feeders in our projected area. Within the area there are six substations sited, but by the information acquires from PEA there only five of them were recorded in SCADA system [9]. Thus, in this simulation we have modeled five substations, named BangLamung (BLA), ChomTien (CHT), PattayaNua (PYN), PattayaTai (PYT) and KhaoMaiKaew (KMK).
Table 3.2: generated profile and peak demand

<table>
<thead>
<tr>
<th>Load profile</th>
<th>Model name</th>
<th>Peak demand [KW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generated Residence#1</td>
<td>House_C</td>
<td>2.9</td>
</tr>
<tr>
<td>Generated Residence#2</td>
<td>House_D</td>
<td>0.5</td>
</tr>
<tr>
<td>Generated Residence#3</td>
<td>House_F</td>
<td>1.2</td>
</tr>
<tr>
<td>Generated Residence#4</td>
<td>House_G</td>
<td>0.5</td>
</tr>
<tr>
<td>Generated Residence#5</td>
<td>House_H</td>
<td>3.4</td>
</tr>
<tr>
<td>Generated Residence#6</td>
<td>House_I</td>
<td>5.8</td>
</tr>
<tr>
<td>Generated Residence#7</td>
<td>House_PF</td>
<td>5.2</td>
</tr>
<tr>
<td>Generated Residence#8</td>
<td>House_PM</td>
<td>1.7</td>
</tr>
<tr>
<td>Generated Residence#9</td>
<td>House_PH</td>
<td>1.8</td>
</tr>
<tr>
<td>Generated Residence#10</td>
<td>House_PT</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Due to the fact that PEA has planned to install around 100,000 units of smart meter to its residential customers for AMI pilot project, we also try to comply with that number as much as possible. With limitation of only twenty seven load models were prepared, the model can only generate 70 percent of total amount with some error on substation profile curves. This error is due to wide variety of actual load which is hardly able to be replicated by a limit number of models.

Figure 3.2: Actual system demand curve and model curve

A year period demand profile of simulated system is calculated with a method mentioned above; also energy consumption profile curve is shown below. Furthermore forecast amounts of demand and consumption are as well illustrated in graphs below;
Figure 3.3: Future peak forecast for BAU and Case1

Figure 3.4: comparison on future energy consumption

The technology selected for generation info calculation are listed below, based on WADE model and Thailand power system, the PDP2010 rev.3 is used as a main information source.

With dispatch order defined, the demand requirement from “feeder model” worksheet is served. The increased capacity forecast done within “generation info” is used to calculate the cost for that capacity which includes installation cost, transmission and distribution expansion cost. In the other way, energy consumption is utilized for O&M cost and fuel cost. Lastly, environmental impact is determined based on energy consumption and emission factor.
Table 3.3: list of selected generation technology and its capacity

<table>
<thead>
<tr>
<th>Generation technology</th>
<th>Base capacity [MW]</th>
<th>Scaled capacity [KW]</th>
<th>Dispatch priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal steam turbine</td>
<td>2,007.00</td>
<td>21,301</td>
<td>6</td>
</tr>
<tr>
<td>Lignite steam turbine</td>
<td>2,180.00</td>
<td>23,137</td>
<td>1</td>
</tr>
<tr>
<td>Oil steam turbine</td>
<td>315.00</td>
<td>3,343</td>
<td>18</td>
</tr>
<tr>
<td>Gas steam turbine</td>
<td>3,714.00</td>
<td>39,417</td>
<td>15</td>
</tr>
<tr>
<td>Combine cycle gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>turbine</td>
<td>16,091.00</td>
<td>170,776</td>
<td>14</td>
</tr>
<tr>
<td>Diesel gas turbine</td>
<td>120.00</td>
<td>1,274</td>
<td>16</td>
</tr>
<tr>
<td>Diesel engine</td>
<td>4.00</td>
<td>42</td>
<td>19</td>
</tr>
<tr>
<td>Hydropower</td>
<td>3,424.00</td>
<td>36,339</td>
<td>2</td>
</tr>
<tr>
<td>Interconnection</td>
<td>2,157.00</td>
<td>22,893</td>
<td>3</td>
</tr>
<tr>
<td>Nuclear power</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal CHP</td>
<td>370.00</td>
<td>3,927</td>
<td>7</td>
</tr>
<tr>
<td>Oil CHP</td>
<td>5.00</td>
<td>53</td>
<td>17</td>
</tr>
<tr>
<td>Gas CHP</td>
<td>1,293.00</td>
<td>13,723</td>
<td>13</td>
</tr>
<tr>
<td>Biomass</td>
<td>1,157.70</td>
<td>12,287</td>
<td>12</td>
</tr>
<tr>
<td>Biogas</td>
<td>57.26</td>
<td>608</td>
<td>8</td>
</tr>
<tr>
<td>Solar PV</td>
<td>10.21</td>
<td>108</td>
<td>9</td>
</tr>
<tr>
<td>Wind turbine</td>
<td>0.51</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Hydro power – small</td>
<td>72.92</td>
<td>774</td>
<td>5</td>
</tr>
<tr>
<td>Waste to energy</td>
<td>9.40</td>
<td>100</td>
<td>11</td>
</tr>
</tbody>
</table>
Table 3.4: Cost factors for each generation technology

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal steam turbine</td>
<td>33,517.80</td>
<td>0.53</td>
<td>67.73</td>
<td>18,642.05</td>
</tr>
<tr>
<td>Lignite steam turbine</td>
<td>32,900.21</td>
<td>0.32</td>
<td>15.62</td>
<td>18,642.05</td>
</tr>
<tr>
<td>Oil steam turbine</td>
<td>24,207.30</td>
<td>0.31</td>
<td>582.44</td>
<td>18,642.05</td>
</tr>
<tr>
<td>Gas steam turbine</td>
<td>13,345.05</td>
<td>0.25</td>
<td>300.34</td>
<td>18,642.05</td>
</tr>
<tr>
<td>Combine cycle gas turbine</td>
<td>17,689.95</td>
<td>0.16</td>
<td>300.34</td>
<td>18,642.05</td>
</tr>
<tr>
<td>Diesel gas turbine</td>
<td>13,345.05</td>
<td>0.13</td>
<td>1,075.39</td>
<td>18,642.05</td>
</tr>
<tr>
<td>Diesel engine</td>
<td>13,345.05</td>
<td>0.75</td>
<td>1,075.39</td>
<td>18,642.05</td>
</tr>
<tr>
<td>Hydropower</td>
<td>59,897.55</td>
<td>0.22</td>
<td>-</td>
<td>18,642.05</td>
</tr>
<tr>
<td>Interconnection</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>18,642.05</td>
</tr>
<tr>
<td>Nuclear power</td>
<td>35,690.25</td>
<td>0.05</td>
<td>22.35</td>
<td>18,642.05</td>
</tr>
<tr>
<td>Coal CHP</td>
<td>35,690.25</td>
<td>0.38</td>
<td>67.73</td>
<td>11,185.23</td>
</tr>
<tr>
<td>Oil CHP</td>
<td>16,448.55</td>
<td>0.48</td>
<td>582.44</td>
<td>11,185.23</td>
</tr>
<tr>
<td>Gas CHP</td>
<td>43,914.53</td>
<td>0.16</td>
<td>238.08</td>
<td>11,185.23</td>
</tr>
<tr>
<td>Biomass</td>
<td>46,273.19</td>
<td>0.36</td>
<td>66.31</td>
<td>11,185.23</td>
</tr>
<tr>
<td>Biogas</td>
<td>126,746.94</td>
<td>1.08</td>
<td>66.31</td>
<td>11,185.23</td>
</tr>
<tr>
<td>Solar PV</td>
<td>41,462.76</td>
<td>0.15</td>
<td>-</td>
<td>11,185.23</td>
</tr>
<tr>
<td>Wind turbine</td>
<td>50,587.05</td>
<td>0.43</td>
<td>-</td>
<td>11,185.23</td>
</tr>
<tr>
<td>Hydro power – small</td>
<td>178,016.76</td>
<td>0.24</td>
<td>-</td>
<td>11,185.23</td>
</tr>
<tr>
<td>Waste to energy</td>
<td>35,690.25</td>
<td>-</td>
<td>66.31</td>
<td>11,185.23</td>
</tr>
</tbody>
</table>

The cost variable in the model is categorized as shown; there are capital cost, O&M cost, fuel cost and T&D expansion cost for each generator. Future costs for capital and fuel costs are adjusted by annual compound growth rate in percent while inflation is excluded. The growth rates are collected from various reports, capital cost for CG was mainly taken from Energy Sector Management Assistance Program (ESMAP) of World Bank group [10] while Thailand data was used for DE system. By the way, O&M and fuel costs are collected from EPPO and international publications [11, 12].

Adopting from WADE model, emission factor for \( NO_x \), \( SO_2 \), and \( PM_{10} \) is collected by technology while it is gathered by fuel type for \( CO_2 \). Various data sources are selected mainly AP42 of United States Environmental Protection Agency (USEPA) [13] and previous work on WADE model [14, 15].
Table 3.5: Emission factor by technology

<table>
<thead>
<tr>
<th>Generation technology</th>
<th>NOₓ [kg/GJ]</th>
<th>SO₂ [kg/GJ]</th>
<th>PM₁₀ [kg/GJ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal steam turbine</td>
<td>0.341</td>
<td>2.218</td>
<td>0.250</td>
</tr>
<tr>
<td>Lignite steam turbine</td>
<td>0.193</td>
<td>1.792</td>
<td>0.026</td>
</tr>
<tr>
<td>Oil steam turbine</td>
<td>0.142</td>
<td>0.946</td>
<td>0.065</td>
</tr>
<tr>
<td>Gas steam turbine/CCGT</td>
<td>0.061</td>
<td>0.0003</td>
<td>0.0008</td>
</tr>
<tr>
<td>Diesel gas turbine/engine</td>
<td>0.079</td>
<td>2.218</td>
<td>0.007</td>
</tr>
<tr>
<td>Coal CHP</td>
<td>0.020</td>
<td>0.020</td>
<td>0.01</td>
</tr>
<tr>
<td>Oil CHP</td>
<td>0.020</td>
<td>0.010</td>
<td>0.003</td>
</tr>
<tr>
<td>Gas CHP</td>
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Table 3.6: CO₂ emission factor

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<th>Fuel Type</th>
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<tr>
<td>Lignite</td>
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</table>
Chapter 3: Scenario development, Assumptions and Limitations

References

[9] PEA load profile of AMRs and Substations in Pattaya area, <information from PEA staff>
Chapter 4: Findings and results

Total required demand and supply

The purpose of this study is to illustrate Smart Grid system ability on saving energy costs in a pilot area. As stated in chapter-3, if there is no smart system or everything is going on BAU case the demand will rise continuously from 304MW to 660MW in 2030. Energy consumption is also double from 2,144GWh to 4,450GWh.

![Figure 4.1: average peak demand (bar graph) and consumption (line graph) projection for BAU case](image)

The figure shows projection of the peak between BAU and Case1 is slightly different as peak reduction applied but the energy consumption is the same as the assumption stated. For other cases the more reduction is shown and even more while energy conservation is used.

Even a small reduction as 5% of peak still affects to capacity share of power plant. Although most of them still maintain the same proportion, the high cost and high emission of peaking plant is eliminated. Figure 4.2 shows that the combine cycle power plant still dominates on overall percentage but others also gain more ratios in the later years.
Chapter 4: Findings and results

Figure 4.2 (a): capacity share of power plant in BAU scenario

Figure 4.2 (b): capacity share of power plant in Case1 scenario

With elimination of peaking plant and shifted demand, intermediate plants can get into more operation. Thus gaining more load factor their operations are economically improved. The generation system improves its load factor from 67.23% to 68.11%.

Economic analysis

The investment cost required for each case is based on increased capacity required either in transmission and distribution system or generation system. By reducing peak demand some of new peaking capacity is avoided. Hence less capital cost for new generation, T&D investment and etc.
If there is no smart system invested it would cost the system on average 7,923 million baht per year to meet the demand. With our assumption of 5% peak reduction without any energy having to be conserved, the cost is reduced about 409 million baht in the first period of 2012-2017. Avoided capital costs will come from avoided generation investment and also less expansion on transmission and distribution system; the amount is listed below;

Table 4.1: Costs comparison in the period of 2012-2017

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<th>Costs [M. Baht]</th>
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<th>Case1</th>
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Figure 4.3: costs comparison for BAU, Case1 and Case1 with EC

The figure shows cost comparisons between Case1 (5% peak shifted) and with EC case. Both cases the smart system cost is fixed at 1,112.14 million baht. Compared to revenue gains from tariff collection within our simulation, the investment in smart system is relatively small.
Environmental impact

Electric power generation is one of the main contributions to air pollutions especially coming from fossil fuel. Pollutants such as CO$_2$, NO$_x$, SO$_x$ and PM$_{10}$ are determined as the main concern in this simulation as stated in chapter-3. Results are shown in figures below;

![Figure 4.4: CO2 average emission results](image)

![Figure 4.5: Other pollutants average emission results](image)

Emission results are observed to be different between BAU and the modified cases. There is, for CO$_2$, a little gap between BAU and Case1 and a much larger gap is with EC although for other pollutants there is not much difference comparing Case1 either with or without EC.
Chapter 4: Findings and results

The results indicate that by reducing peak demand through smart system, contribution to environmental protection is made.

Conclusion

As Smart Grid is being developed and deployed around the world, Thailand also initiates its first Smart Grid program through PEA. With profound contribution of WADE economic model on DE field, an extension for Smart Grid model is an objective for this study. Most of Smart Grid deployment around the world started with AMI projects and so with PEA as it announced the pilot project in Pattaya City. The model was developed so that it could represent that city with some dynamic response on the load side assuming smart system implementation.

Using WADE model as the base-model, an extended model composed of several composites is defined with data collection from actual load profiles and feeder profiles. Twenty seven load models were defined and combined representing demand system in the area of interest. The WADE model is used for its generation information and parameters. Three scenarios are made to elaborate the system reaction to modification added such as BAU scenario, peak shifting without energy conservation and peak shifting with energy conservation scenarios. Sensitivity cases are also formulated by varying peak reduction percentage of 5 to 15 percent. Some assumptions are made as stated in Chapter-3. The model time frame forecast of up to 2030.

This simulation model demonstrates substantial benefit of Smart Grid system in the pilot area. By introducing peak reduction, the model shows benefits in both economic and environmental aspects. The reference scenario of BAU and 5% peak reduction is developed and the results show encouraging benefit in the decline of cost with some reduction in pollutant emissions.
Appendix A

Figures of worksheet stated in chapter-3 are shown in this section as listed below; Most of them are not completely shown due to the fact that size of worksheet employ large area that cannot fit into a page here. So to simply illustrate how it is looked there are some hidden areas within sheets suppressing the excessive detail.

   a) Load model worksheet
   b) Feeder model worksheet
   c) Feeder financial worksheet
   d) Generation info worksheet
   e) Generation finance worksheet
   f) Emission calc worksheet
   g) Outcome
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#### Load factor

- **Load factor:** The load factor is a measure of the variation in energy consumption over time. It is calculated as the ratio of the average demand to the peak demand over a given period.

#### Load requirement

- **Load requirement (peak):** The peak load requirement is the maximum power capacity required to meet the highest demand at any point in time.

#### Load shift

- **Load shift:** The load shift is the difference between the peak and off-peak demands, indicating how much demand is shifted during off-peak periods.

#### Advanced metering infrastructure cost

- **Advanced metering infrastructure:** Advanced metering infrastructure (AMI) refers to the communication system used to collect and transmit energy usage data from homes or businesses to utility companies. The cost can vary significantly depending on the technology and implementation strategies.

---

### Table Values

- **Load factor:** Various load factors are provided, ranging from 0.29 to 0.96.
- **Load requirement (peak):** Peak load requirements range from 15.57 kW to 219.00 kW.
- **Load shift:** Load shifts are calculated for different scenarios, ranging from 0.02 kW to 32.24 kW.
- **Advanced metering infrastructure cost:** Costs range from $0 to $30,957 per unit.
### b) Feeder model worksheet

| Case/DC | peak load | conserve | MWh | D | L | F | G | H | J | K | L | M | N | O | P | Q | R | S | T | U |
|---------|-----------|----------|-----|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|         | [kW]      | [kWh]    | [kW] | [MW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] | [kW] |
| 1       |           |          |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 2       |           |          |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 3       |           |          |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 4       |           |          |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

**Substitution**

- **Victor-1**: 116.246 kWh
- **Victor-1**: 116.246 kWh
- **Victor-1**: 116.246 kWh
- **Victor-1**: 116.246 kWh

**Load multipliers**

- **Victor-1**: 116.246 kWh
- **Victor-1**: 116.246 kWh
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**Load attached**

- **Victor-1**: 116.246 kWh
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**Peak load**

- **Victor-1**: 116.246 kWh
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Appendix A

(Feeder model cont.)
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### Peak demand

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### Current yearly consumption

- **Peak:** 1,286.25 kWh
- **Total:** 636.22 kWh
- **Off-peak:** 1,190.48 kWh
- **Total:** 2,076.73 kWh

### Total yearly on-peak consumption

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### Notes:

- **Feeder Financial Worksheet**:
  - Includes detailed financial data for various substations and feeders, including installation costs, operational and maintenance (O&M) costs, and financial terms.
  - Key columns cover:
    - Substation
    - Feeder
    - Dist. Transformer
    - Tariff plan
    - Voltage level
    - Load multiplier
    - Incremental Instrument capacity
    - Installation cost (kW, kW/kWh)
    - Avg. Yearly Increase (Reduction) in costs (%)
    - [%] of [%]
    - Financial term (years)
    - O&M cost (kW/kWh)
    - Total Capacity Investment (kW/year)
    - Total O&M cost (kW/year)
  - The table lists data for various substations, feeders, and transformers, providing a comprehensive overview of financial considerations for each.
### Appendix A

#### Feeder financial cont.

| BI | BJ | BK | BL | BZ | CA | CB | CC | CD | CG | CH | CI | CJ | CK | CL | CY | C2 | DM | DN | EA | EB | EV | EW |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
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- **Stations:**
  - Diesel Engine 16

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## Appendix A

### (Generation info cont.)

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<td>519,323</td>
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<td>2021</td>
<td>512,613</td>
<td>560,163</td>
<td>609,269</td>
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- **Current Capacity [kW]**
  - 2019: 434,232
  - 2020: 503,954
  - 2021: 512,613

- **Future Capacity [kW]**
  - 2019: 436,381
  - 2020: 519,323
  - 2021: 560,163

- **Current Efficiency [%]**
  - 2019: 10.6%
  - 2020: 11.3%
  - 2021: 10.6%

- **Future Efficiency [%]**
  - 2019: 10.6%
  - 2020: 11.3%
  - 2021: 10.6%

- **Total Capacity [MW]**
  - 2019: 434,232
  - 2020: 503,954
  - 2021: 512,613

- **Total Efficiency [%]**
  - 2019: 10.6%
  - 2020: 11.3%
  - 2021: 10.6%
## e) Generation finance

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<td>-</td>
<td>360</td>
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<td>360</td>
<td>11,105.23</td>
<td>4.8%</td>
<td>10</td>
<td>0.45</td>
<td>1.8</td>
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## Generation finance cont.

<table>
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<th>Year</th>
<th>Total O&amp;M cost (M$)</th>
<th>Total Fuel cost (M$)</th>
<th>Total T&amp;D investment cost (M$)</th>
<th>Average increase in price per unit produce (Baht/kWh)</th>
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### Appendix A

#### f) Emission calc

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<th>Heat rates</th>
<th>CO2 emission factor (kg/ton)</th>
<th>NOX</th>
<th>SOX</th>
<th>PM10</th>
<th>Daily CO2 emission (kg)</th>
<th>Daily NOX emission (kg)</th>
<th>Daily SOX emission (kg)</th>
<th>Yearly CO2 Emission (Ton)</th>
<th>Yearly NOX Emission (Ton)</th>
<th>Yearly SOX Emission (Ton)</th>
<th>Yearly PM10 Emission (Ton)</th>
<th>Future CO2 Emission (Ton)</th>
<th>Future NOX Emission (Ton)</th>
<th>Future SOX Emission (Ton)</th>
<th>Future PM10 Emission (Ton)</th>
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</table>

**Table Data:**

- **CO2:**
  - Total: 2,358,116.14 kg
  - 2010: 4,681,593 kg
  - 2011: 2,522,795 kg
  - 2012: 1,570,499 kg
  - 2013: 785,710.02 kg
  - 2014: 1,344.14 kg
  - 2015: 6,388.89 kg
  - 2016: 417.13 kg
  - 2017: 821,161.33 kg
  - 2018: 1,391.16 kg
  - 2019: 5,975.95 kg
  - 2020: 10.61 kg

- **NOX:**
  - Total: 1,054.848 kg
  - 2010: 7,986.978 kg
  - 2011: 2,977.787 kg
  - 2012: 1,554.848 kg
  - 2013: 749,710.02 kg
  - 2014: 1,323.82 kg
  - 2015: 6,270.23 kg
  - 2016: 422.63 kg
  - 2017: 821,161.33 kg
  - 2018: 1,387.10 kg
  - 2019: 3,959.08 kg
  - 2020: 406.61 kg

- **SOX:**
  - Total: 64,645.192 kg
  - 2010: 10,269.614 kg
  - 2011: 5,158.747 kg
  - 2012: 3,156.741 kg
  - 2013: 2,141.161 kg
  - 2014: 1,413.18 kg
  - 2015: 942.33 kg
  - 2016: 668 kg
  - 2017: 490,515.88 kg
  - 2018: 534.84 kg
  - 2019: 2.67 kg
  - 2020: 2.67 kg

- **PM10:**
  - Total: 6,667.00 kg
  - 2010: 6,667.00 kg
  - 2011: 6,667.00 kg
  - 2012: 6,667.00 kg
  - 2013: 6,667.00 kg
  - 2014: 6,667.00 kg
  - 2015: 6,667.00 kg
  - 2016: 6,667.00 kg
  - 2017: 6,667.00 kg
  - 2018: 6,667.00 kg
  - 2019: 6,667.00 kg
  - 2020: 6,667.00 kg

- **Future Emissions:**
  - CO2: 2,358.11614 Ton
  - NOX: 1,054.848 Ton
  - SOX: 64,645.192 Ton
  - PM10: 6,667.000 Ton

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**Appendix A**

**g) Outcome**
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<th>Z</th>
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Appendix A

(Outcome cont.-top right part)
### Appendix A

#### (Outcome cont.-bottom left part-)

| 81 | House 12 [House 12] | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 82 | lead factor (demand) | [kW] | 76.91% | 77.92% | 78.98% | 79.27% | 79.27% | 79.27% | 79.27% | 79.41% | 79.41% | 79.36% | 79.75% | 79.36% | 79.75% |
| 83 | lead factor (source) | [kW] | 67.23% | 68.11% | 69.59% | 69.29% | 68.11% | 69.29% | 69.29% | 67.40% | 68.28% | 69.12% | 69.46% | 68.28% | 69.12% |
| 84 | average peak demand | [kW] | 374,992 | 370,143 | 365,647 | 363,948 | 351,368 | 347,365 | 345,666 | 491,112 | 479,091 | 469,123 | 468,014 | 452,146 | 443,666 |
| 85 | average energy consumption | [kWh] | 2,525,864 | 2,525,864 | 2,525,864 | 2,525,864 | 2,399,571 | 2,399,571 | 2,399,571 | 2,399,571 | 2,320,492 | 2,320,492 | 2,320,492 | 2,320,492 | 2,320,492 |
| 86 | average energy consumption growth | [%] | 4.68% | 4.68% | 4.68% | 4.68% | 4.68% | 4.68% | 4.68% | 4.68% | 4.68% | 4.68% | 4.68% | 4.68% | 4.68% |
| 87 | average transmission losses | [kWh] | 98,095 | 98,095 | 98,095 | 98,095 | 98,095 | 98,095 | 98,095 | 98,095 | 126,521 | 126,521 | 126,521 | 126,521 | 126,521 |
| 88 | average distribution losses | [kWh] | 3,224 | 3,224 | 3,224 | 3,224 | 3,224 | 3,224 | 3,224 | 4,446 | 4,446 | 4,446 | 4,446 | 4,446 | 4,446 |
| 89 | peak reduced | [kW] | (8,849) | (9,345) | (11,144) | (12,356) | (27,672) | (29,337) | (29,337) | 8,221 | 8,790 | 10,419 | 12,272 | 13,176 | 13,769 |
| 90 | peak factor improve | [%] | -2.13% | 2.49% | -2.37% | -4.23% | -7.37% | -7.82% | -7.82% | -1.29% | -2.99% | -2.99% | -2.99% | -7.37% | -7.82% |
| 91 | total cost saving | [M [Bahn]] | 77,549.06 | -45,087.11 | -44,962.41 | -44,156.70 | -41,250.37 | -40,943.45 | -40,781.65 | 77,129.13 | 69,743.76 | 68,700.34 | 68,365.87 | 68,144.01 | 61,714.98 |
| 92 | required cost | [M [Bahn]] | 233.82 | 233.82 | 233.82 | 233.82 | 233.82 | 233.82 | 233.82 | 233.82 | 233.82 | 233.82 | 233.82 | 233.82 | 233.82 |
| 93 | investment cost | [M [Bahn]] | 2,222.42 | 2,647.12 | 2,372.83 | 2,966.17 | 3,866.13 | 5,527.51 | 7,147.95 | 8,161.37 | 8,525.84 | 14,427.70 | 15,116.72 | 15,405.11 |

**Notes:**
- In columns, values are presented in descending order for each row.
- The table provides a detailed analysis of energy consumption and various factors contributing to cost savings in different scenarios.
- The values indicate percentage changes and energy consumption metrics for each house, aiding in understanding efficiency and cost implications.
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(Outcome cont.-bottom right part)