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A Load Prioritization Model for a Smart Demand Responsive Energy Management System in the Residential Sector

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Abstract

In order to strengthen energy security while reducing environmental impact, particularly from global warming and greenhouse gas (GHG) emissions, the government of Thailand has established a 20-year Energy Efficiency Development Plan (EEDP), aiming to reduce a 20 % share of final energy consumption by 2030. The energy saving potential assessment reveals that the forecasted energy saving by the residential sector holds more than 60 % of the overall electricity saving shares. Therefore, in this paper, the situation of Thailand's energy is presented and the energy conservation plan is reviewed. Next, a smart demand responsive energy management system under ZigBee/IEEE 802.15.4 based wireless communication is proposed. An analysis of demand response potential in terms of a time-of-use (TOU) pricing without enabling technology program in Thailand scenario is also investigated. Finally, by using the proposed load characterization and load prioritization under the concept of a smart energy management system, the bill savings benefits of a demand responsive program can be proved while the target of energy saving is also achieved.

Keywords: Energy conservation, energy efficiency, demand responsive management, ZigBee, wireless sensor network, residential sector

Introduction

Being heavily dependent on imported oil, Thailand, a developing country located in the middle part of Southeast Asia, has established policies to encourage bio-fuels, cogeneration, and the generation of power from renewable energy. Energy is an important factor in daily living for improving the quality of life and for the economic development of a country. In particular, the energy demand in Thailand has been increasing continuously. In addition, it is projected that energy prices will be constantly on the rise, hence creating a greater burden on energy consumers and affecting economic competitive edge. Apart from energy problems, Thailand has to face a further challenge from the environmental impact caused by the use of energy, particularly the impact of climate change resulting from global warming and greenhouse gas (GHG) emissions. Therefore, the energy policies outline the main mission of the Ministry of Energy; to devote its efforts to promote energy security, support alternative energy development, and maintain the fairness and the stability of energy market [1]. Currently, it is internationally accepted that energy conservation and energy efficiency improvement are important approaches to address the aforementioned challenges. Consequently, the Thai government has introduced the 20-year Energy Efficiency Development Plan (EEDP) for the years 2011 - 2030 [2], which set a target to reduce energy intensity by 25 % in 2030, compared with that in 2005, or equivalent to a reduction of final energy consumption by 20 % in 2030.

This paper reviews Thailand's energy scenario in terms of the 20-year energy plan. Based on the outcome of energy saving potential assessment, the transportation and industrial sectors together hold the highest energy saving share, at over 80 % in terms of final energy. In terms of electricity saving potential, the commercial building and residential sector holds more than 60 % of the overall electricity saving shares. Therefore, a smart demand responsive energy management system for residential application in Thailand will be proposed in both system structure and communication technology. Details of load characterization and load prioritization are also mentioned. Finally, simulation results related to load shifting, based on time of use pricing, will be given, in addition to a description of bill saving benefits.

Thailand energy demand situation 2012

In 2012, demand for electricity in Thailand grew at an accelerating rate [3]. The net peak generation requirement on the Electricity Generation Authority of Thailand (EGAT) system rose to 26,121.1 MW on 26 April 2012, higher than that of the preceding year by 2,220.9 MW [4]. **Figure 1** shows the electricity consumption for the whole country in 2011, classified by sector i.e. residential, business, industry. The electricity consumption used by the industrial sector is much higher than others at 67,784 GWh or accounting for 46.21 %. The second rank is held by the residential sector, accounting for 32,799 GWh or 22.36 % of the overall electricity consumption of the country [5].

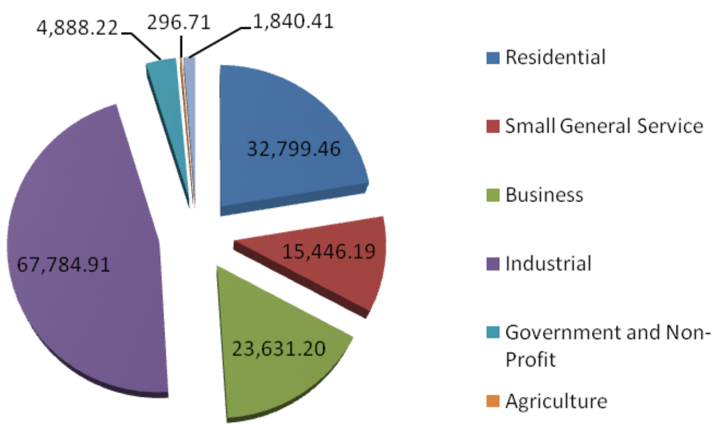

Figure 1 Electricity consumption for the whole country classified by Sector (Unit: GWh) [5].

Energy efficiency development plan: Background and objectives

In response to this rapid growth and the requirements in developing regulations for Thailand's energy sector, the Energy Policy and Planning Office (EPPO) took the main responsibility for giving advice and formulating policies and measures to drive the country's energy development, including the formulation of the 20-year Energy Efficiency Development Plan (EEDP), with the following 2 main objectives;

(1) To set the energy conservation targets in the short term (5 years) and in the long term (20 years), both at the national level and by energy-intensive economic sectors, i.e. transportation, industry, commercial and residential sectors.

(2) To lay down strategies, guidelines and work plans to serve as the framework for concerned agencies in formulating their respective action plans for energy conservation.

Energy conservation Targets and Potential in EEDP

In the next 20 years, if there is no energy conservation or energy efficiency improvement measures, or no significant reform of the industrial structure and transportation system, energy demand under the business-as-usual (BAU) scenario will increase by about 2.1 times the present amount, accounting for an annual average growth rate of 3.9 %. The demand in the industrial and commercial sectors will still increase at a higher rate than other sectors. Hence, greenhouse gas emissions from the energy sector will tend to increase accordingly. In regard to these foreseen problems, the study team has assessed the energy conservation potential, in technical terms, of 3 major economic sectors, i.e. transportation, industry, commercial building and residential sectors, so as to develop the energy conservation targets in the next 20 years, and to analyze the various energy conservation promotion measures.

Table 1 Energy saving potential by economic sector in 2030 [1].

Economic Sector	Technical Potential			Specified Target (ktoe)	Share (%)
	Heat (ktoe)	Electricity (GWh)	Total (ktoe)		
Transportation	16,250	-	16,250	13,400	44.7
Industry	10,950	33,500	13,790	11,300	37.7
Commercial Building & Residential					
- Large Commercial Building	410	27,420	2,740	2,300	7.6
- Small Commercial Building & Residential	1,690	23,220	3,670	3,000	10.0
Total	**29,300**	**84,140**	**36,450**	**30,000**	**100.0**

The outcome of the energy saving potential assessment is shown in **Table 1**. It reveals what the share of forecasted energy saving by sector in 2030 will be, with the transportation and industrial sectors together holding the highest energy saving share, i.e. over 80 % in terms of final energy. For electricity saving potential, the commercial building and residential sector holds more than 60 % of the overall electricity saving shares, which is the largest share and plays an important role in achieving the specified energy conservation target. In this research, the goal is to design a methodology for a residential demand response program to be implemented in a proposed smart energy management system mainly in residential groups, so that the assessment of energy conservation potential of this group will be more focused.

Table 2 Electricity saving potential in the small commercial building and residential group [1].

Equipment	Demand in 2030 BAU case (GWh)	Percentage of energy saving (%)	Electricity saving potential in 2030 (GWh)	Electricity saving potential in 2030 (ktoe)
Lighting category				
Fluorescent tube	5,222	30	1,573	134
Electronic ballast	1,596	90	1,450	124
Compact fluorescent bulb	320	80	257	22
Comfort category				
Air-conditioner	25,901	50	13,325	1,135
Water heater	6,614	100	6,614	564
Total			23,219	1,978

The assessment of energy conservation potential in EEDP is mainly based on the forecast utilization of higher energy-efficient equipments/appliances, for which energy utilization is divided into 5 categories as follows: fluorescent tubes, electronic ballasts, compact fluorescent lamps, air-conditioners and water heaters. In this regard, the overall energy conservation potential in the commercial building and residential sector in 2030 can be summarized in **Table 2**. Although using high energy-efficiency appliances provides a high energy saving potential, the government still needs to put more effort into promoting, supporting and encouraging end-users to voluntarily use high energy-efficiency appliances. Besides changing equipment, putting forth the concept of energy conservation by fostering public awareness and changing their energy consumption behavior is very important.

Materials and methods

The proposed smart demand-responsive energy management system in residential sector

Demand response [6-8] can be defined more specifically as changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high price. This research aims to propose an analysis of demand response potential in terms of a time-of-use (TOU) pricing without enabling technology program in Thailand scenario. TOU rates fall under static time-varying rates. Prices are higher during peak periods to reflect the higher-than-average cost of providing electricity during those times, and lower during off peak periods, when it is cheaper to provide the electricity. That is, the peak period of the Thai power system is during 09.00 - 22.00 h from Monday to Friday and the off-peak is during 22.00 - 09.00 h from Monday to Friday and the whole day on Saturday, Sunday and public holidays. The time of use rate in Thailand is as shown in **Table 3**. It can be seen that during peak hour the demand charge is at 5.2674 Baht/kWh, while during off-peak demand the demand charge is at 2.1827 Baht/kWh for Voltage lower than 22 kV, which is mainly used in the residential and small business sectors.

Table 3 Time of use rate in Thailand

Time of use rate	Energy charge (Baht/kWh)		Service charge (Baht/Month)
	Peak	Off Peak	
22 - 33 kV	4.5827	2.1495	312.24
Below 22kV	5.2674	2.1827	38.22 (Residential) 46.16 (Small business)

Note: Peak — The time from 09:00 - 22:00 Mon. - Fri. and Royal Ploughing Day
Off Peak — The time from 22:00 - 09:00 Mon. - Fri. and Royal Ploughing Day and the time from 00:00 - 24:00 Sat. - Sun., Labor Day, Royal Ploughing Day which falls on Sat. and Sun., and Official Holidays (Not include Compensatory Holiday)

Thailand residential electricity consumption

According to Thailand's power demand in provincial areas collected by Ministry of Energy, it is shown that the total demand in the residential sector in 2011 was 32,920 GWh and accounted for 22.1 % of the total electricity consumption [9]. The Provincial Electricity Authority (PEA) household consumer demand is classified into 2 categories; consumers which use less than 150 kWh/Month and consumers which exceed 150 kWh/Month. In this research, household consumers which exceed 150 Unit/Month, which is the majority group of PEA customers, were selected and monitored. As an example, the load profile of the residential sector in November, 2012 is illustrated in **Figure 2**. It is divided into different days, such as peak day, Sunday, Saturday and work day. The monitored data shows that the peak load is located in the evening during 19.00 - 21.00 h and the high demand also occurs in the morning during 06.00 - 07.00 h. The household load profile obviously has almost the same pattern across the country.

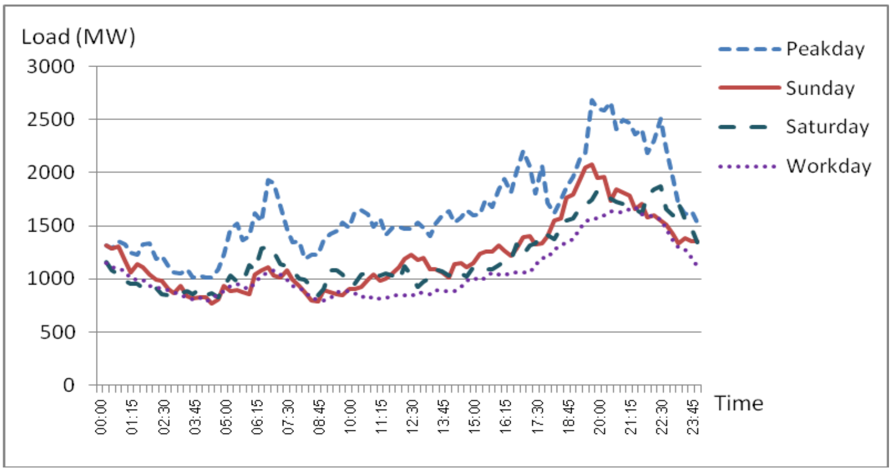

Figure 2 24 h household load profile operated by PEA.

Load characterization and load prioritization on demand response action

This section will focus on the load characterization based on existing loads in Thai households, collected from surveys. The Thai government has not yet determined the energy performance standard of the small commercial building and residential group. Therefore, in this research, load characterization will be analyzed into 7 groups as following;

(1) Lighting group: fluorescent tubes and incandescent bulbs;

(2) News, entertainment and office equipment group: televisions, VDO/VCD/DVD players, stereos, radios and computers;

(3) Cooking appliance group: rice cookers, electric stoves, microwave ovens, refrigerators;

(4) Washing machines: clothes-washing machines, dishwashers;

(5) Air-conditioning systems;

(6) Heating appliance group: Electric water heater and electric iron;

(7) Others: loads such as electronic equipments, tablet chargers, and mobile phones chargers.

In order to implement a demand responsive program, load prioritization will be discussed, so that a smart demand system can prioritize loads in a household whether the system can automatically perform actions, for example shifting some loads to off peak periods resulting in electricity bill saving, do not let members use some loads during peak periods unless given permission from the system, or reset parameters in order to reduce energy usage during peak periods. The prioritization of target domestic loads is done based on technical limitations of the loads, and also relies on the adaptability and flexibility of end-users to let the target loads be automatically controlled. Consequently, the automated demand response system can appropriately manage target loads in households which depend on load prioritization. According to loads' technical restrictions and end-users' flexibility from the surveys, load prioritization can be divided into four groups, which are Uncontrollable loads, Reparameterizable loads, Interruptible loads, and Shiftable loads [10-12];

- Uncontrollable loads: loads that cannot be the target of any type of automated demand response actions.

- Reparameterizable loads: loads that thermostatically controlled by temperature parameters.
- Interruptible loads: loads that can be interrupted during a short period and at a certain point of their working cycle.
- Shiftable loads: loads that can be used in another period of the day and therefore can have the working cycle anticipated or postponed.

From the surveys, there are appliances which consume considerable electricity but cannot be controlled or shifted to off peak period, such as lighting, entertainment and office equipment, and cooking appliances. Those categories is intensely related to the end-users' needs; therefore, they are categorized into uncontrollable loads, because they should be provided whenever desired. Air conditioning systems, refrigerators, and electric water heaters are appliances which can be reparametized and interrupted without restarting the working cycle. Thermos and fans can be interrupted whenever required. Washing machines can be shifted to work in off peak times by the system without bothering household members. Other appliances such as electronic charging devices, irons, etc. can be reorganized by shifting loads or interrupting in order to avoid peak time, resulting in a cost reduction of the electricity bill. Common domestic loads in Thailand obtained from the surveys can be prioritized into the aforementioned 4 types of control which are shown in **Table 4**.

After dividing loads into 4 groups, demand responsive programs can be implemented in order to shift unnecessary loads to off peak periods. Shiftable control and interruptible control loads can be automatically shifted to off peak periods. Some loads that cannot operate by the system will be advised for use in off peak times, such as irons. For reparameterizable loads, if necessarily used in peak times, the system will automatically alter parameters of appliances in order to reduce energy usages, and, if possible, will interrupt the loads.

Table 4 Type of control of domestic loads.

Domestic loads	**Type of control**			
	Uncontrollable loads	**Reparameterizable loads**	**Interruptible loads**	**Shiftable loads**
Lighting	■			
Entertainment Equipment	■			
Office Equipment	■			
Microwave Ovens	■			
Cooking Machines	■			
Air Conditioners		■	■	
Refrigerators		■	■	
Electric Water Heaters		■	■	
Thermos			■	
Fans			■	
Electronics Charging Devices			■	■
Irons			■	■
Coffee Maker			■	■
Vacuum Cleaner			■	■
Hair Dryer			■	■
Clothes Washing Machine				■

The structure of smart demand-responsive energy management system

Being a part of smart grid implementation in Thailand, according to PEA Strategic Objectives [13], the Smart Grid project is clearly stated as part of new and appropriate technology in order to increase the organization's performance and utilization. The plan is for Thailand's Smart Grid to overlay the conventional electrical grid with an information and net-metering system that includes smart meters. PEA Smart Grid includes an intelligent monitoring system that keeps track of all the electricity flowing through the system but in greater detail. It can also integrate renewable forms of energy such as solar and wind power but more effectively than before.

Within the concept of a demand responsive program, energy management in the residential sector is one of the sectors attracting interest from the researchers [14,15]. Although it might be hard to handle the large numbers of residential units, the impact of demand response program is considered to be relatively small when compared with their implementation cost. However, under the PEA smart grid, with the mentioned smart meter, it is possible to set the stage for novel residential smart demand responsive energy management systems to be implemented in Thailand.

The structure of smart energy management system

This section is primarily focused on the concept of the proposed energy management and monitoring system, which employs an over the wireless sensor in a home area network. Therefore, in this research, a guideline and implementation of a smart energy-usage monitoring and management system is studied. The monitoring system is based on the 2.4 GHz wireless sensor network under ZigBee/IEEE 802.15.4 Standard. The new platform allows end-users to locally monitor, control and compare electricity consumption of selected appliances connected to a residential power network. **Figure 3** shows the smart home which has the home energy management unit built in [16].

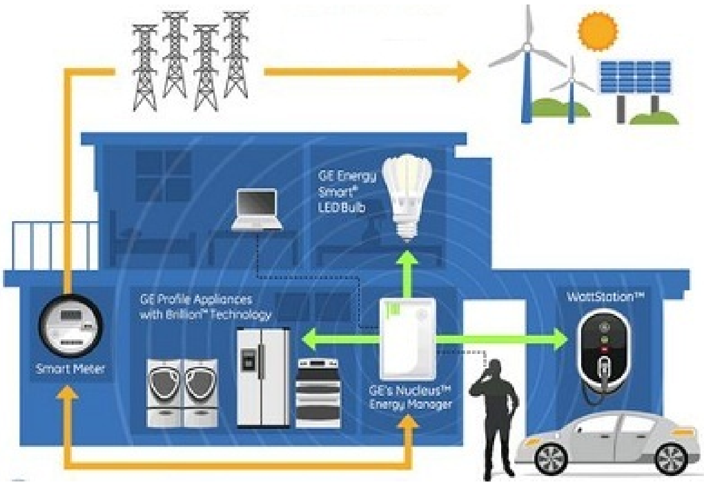

Figure 3 Example of smart residential energy management system [16].

ZigBee based wireless communication technologies

IEEE 802.15.4 standard [17,18] defines the protocol and interconnection of devices via radio communication in a personal area network (PAN). It operates in the ISM (Industrial, Science and Medical) radio bands, at 868 MHz in Europe, 915 MHz in the USA and 2.4 GHz worldwide. The purpose is to provide a standard for ultra-low complexity, ultra-low cost, ultra-low power consumption and low data rate wireless connectivity. ZigBee technology may be used in various applications in controls, embedded sensors, including building and home automation, and others. Based on these features provided by IEEE 802.15.4/ZigBee, ZigBee technology is very suitable for these smart energy demand responsive energy management applications.

The proposed ZigBee based smart energy management system framework is made up of data collection nodes and a PAN network coordinator. Each node will be connected to each in-home appliance and then can carry out desired functions from different nodes, such as detecting energy usage signals, controlling the on-off switch, sending timestamps, signal quantizing, and simple processing, and the ZigBee/IEEE802.15.4 Standard package framing can transmit data to the PAN network coordinator. Upon receiving that energy usage data via the PAN network coordinator, the base station will upload the incoming data to MCU for further processing and analysis. An advanced smart energy management system algorithm will be used for analyzing the data to determine the status of the demand responsive action to each appliance and suggest possible action to control and manage the energy usage in order to follow the designed load-shaping strategies.

Therefore, by applying the smart demand responsive energy management system, the load-shaping could be achieved and the energy consumption during peak hours could be decreased. Moreover, the end-users would be able to continuously monitor domestic consumption from different appliances and then make an overall optimization of electricity usage based on their own information, eventually resulting in behavioral change.

Results and discussion

Impact on residential load profile

To illustrate the demand response potential estimations at the household level, a survey has been conducted in around 30 households of Walailak University colleagues that are PEA customers. A simulation-based assessment of the impact of implementing demand responsive actions over manageable demand was also carried out, highlighting the need of smart demand responsive energy management. Considering the example of one household with high electricity usage (more than 500 kWh/Month), the load profile is as shown in **Figure 4**; it is obvious that members of this household always use appliances during peak time from 19:00 to 22:00. Moreover, mostly high energy-consuming appliances were used, such as an air conditioner, an iron, a cloth washing machine, and a hair dryer. The electricity billing of this household is 2677.3 Baht, at 737.59 units of energy usage.

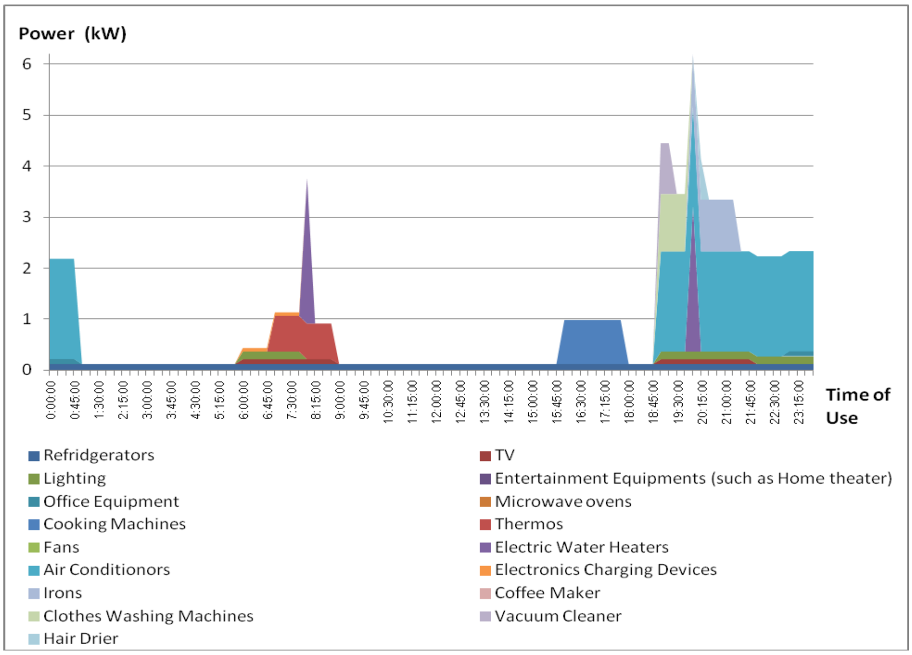

Figure 4 Example of load profile from one household in Walailak University.

By applying the demand responsive energy management system based on the proposed wireless energy usage monitoring and home-appliance smart controlling system, the consumer would be able to set or shift the working period of those high energy-consuming appliances and could make an overall optimization of electricity usage based on the time of use rate. Some energy management concepts could also be applied; for example, using cooling fans instead of air conditioners during peak time from 09:00 until 22:00, or setting the smart energy management system to turn on the air conditioner after 22:00 without interrupting household members during sleeping time. Ironing clothes is also one of the behavioral actions that need to be changed. In accordance with the results from surveys, people usually press clothes during peak time, and they are unwilling to change this time to off-peak periods such as 7:00 - 9:00 in the morning, 22:00 - 24:00 before sleeping time or during the weekend if it potentially reduces electricity bills. It is also interesting that most household members also use washing machines in peak time. Nevertheless, they are willing to shift the working period of washing machines to off-peak times if they have fully automatic controlling systems; then they could wash or dry clothes during predefined configurations.

Bill savings benefits

Electricity bill savings are earned by customers that adjust loads in response to current time-of-use rates. It is a direct bill saving for participant customers. By applying the proposed load characterization and prioritization based on smart demand responsive energy management system, the comparison of load profiles between business-as-usual and the proposed program is illustrated in **Figure 5**. We can see from a household sample that after implementing the demand responsive program, the peak load that was previously located during 19.30 - 20.00 is automatically shifted into the off peak period.

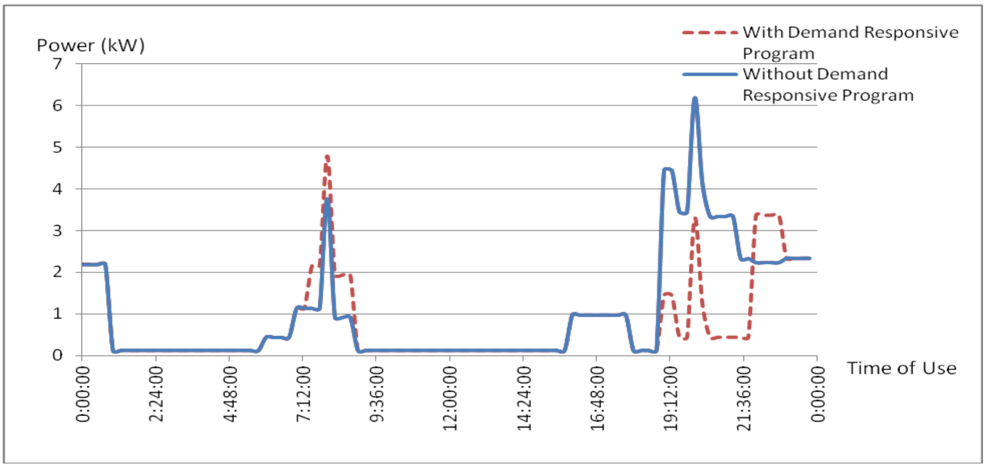

Figure 5 Comparison of load profiles before and after applying demand responsive program from one household.

Moreover, after implementing the demand responsive program to target households, then recalculating electricity bills by using the time of use rate instead of the normal energy charge rate, there are 3 types of household samples found; these were investigated as presented in **Table 5**. Household sample No.1 represents the benefit mainly earned from time of use rate. Without load shifting, the electricity bill is reduced from 2226.64 baht to 1680.2 baht, which is a 24.54 % bill saving, even though the energy usage is still the same amount at 623.10 kWh. Household sample No.2 shows the effectiveness of the load shifting method based on the proposed smart energy management system; by applying load characterization and prioritization considered with time of use rate, the electricity bill is decreased from

2677.30 baht to 1763.40 baht, which is 34.13 % reduction, and the energy usage also reduces from 737.59 kWh to 567.36 kWh due to the predefined energy conservation program. Household sample No.3 represents that the electricity bill could also increase, such as in this case, from 1178.60 baht to 1241.2 baht which is 5.31 % higher. This result will happen with the household sample which has a low amount of energy usage and where most loads are uncontrollable-type appliances which are used by household members only during peak periods.

We can conclude that time of use pricing rates by definition will result in some customers experiencing bill increases due to their higher-than-average peak consumption patterns, and these customers may not opt-in to such a rate if it is only offered on a voluntary basis. However, when accounting for moderate shifting of load from peak to off-peak periods, such rates could become financially attractive for a larger segment of customers.

Table 5 Comparison of electricity bills before and after implementing demand responsive program.

Household sample No.	Without demand responsive program		With demand responsive program		Percentage of bill saving (%)
	Energy used (kWh)	Electricity billing cost (Baht)	Energy used (kWh)	Electricity billing cost (Baht)	
1	623.10	2226.64	623.10	1680.2	24.54
2	737.59	2677.30	567.36	1763.4	34.13
3	356.84	1178.60	356.84	1241.2	-5.31

Additionally, once the implementation of a demand responsive energy management program has been done by simulation of randomly selected on 10 surveyed households, the result is quite interesting; the proposed load characterization and prioritization can achieve in total a 14.05 % reduction of the electricity billing cost and a 6.53 % reduction of energy usage. **Figure 6** shows the load profiles of overall household samples before and after applying demand responsive program without enabling any new technology. Therefore, the smart demand responsive program is an incentive to be presented in order to lower electricity costs and also total potential peak reduction. Furthermore, it can be seen that at the national level the largest gains in demand response impacts can be made through these pricing programs when they are offered with enabling technologies.

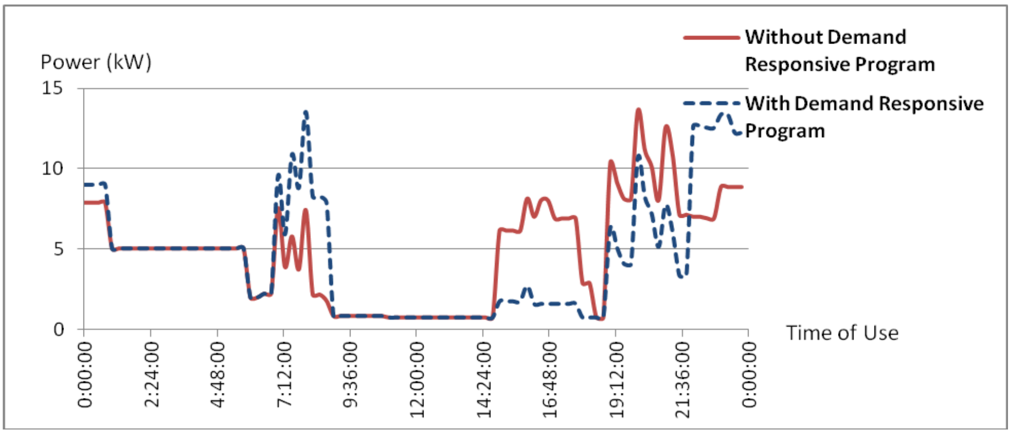

Figure 6 The potential of demand responsive program: with and without implementation.

Others indirect benefits

Moving from the normal energy usage to the demand responsive scenario, not only could the peak demand in households be reduced, but the difference seen is also attributable to the incremental potential for pursuing the potential in terms of a time-of-use (TOU) pricing without enabling technology program in Thailand scenario. Moreover, **Figure 6** implies that if a smart demand responsive program is effectively applied to the overall households, electricity usage from residential and small commercial building during peak demand will be shifted to off peak periods, resulting in some unnecessary power plant projects that the Electricity Generating Authority of Thailand need to invest in possibly being postponed.

Conclusion

In this paper, the smart demand responsive energy management system under ZigBee based wireless communication is proposed. The opportunities and challenges for the Thai residential sector are discussed. The analysis of demand response potential in terms of a time-of-use (TOU) pricing without enabling technology program in Thailand scenario is also investigated particular to the residential group. By applying the proposed load characterization and load prioritization under the concept of an energy management system, the bill savings benefits of a demand response program can be proved. To implement the price-based demand response practically, the wireless and smart metering capability, including data management systems, need to be in place, and they are necessary for all customers. Results from this study could also help in terms of energy management and planning in the future. It is also helpful for PEA to provide optimum electricity for household. In order to achieve the energy savings target as set in the 20-year EEDP, concurrently, new energy technologies that have been proven in other countries should be considered and deployed for application to Thailand. Furthermore, both energy efficiency and demand response principles should be included and coordinated in education programs and action plans, to broaden household consumer understanding, improve results and use demand-responsive program resources effectively.

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