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Residential loads management by considering households' satisfactory levels for smart meter applications

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Abstract:
In order to aim the target of using green energy resources in many countries, not only are energy harvesting technologies installed but demand side energy management has to be also implemented. With the fact that different person has different lifestyle; therefore, in this paper, satisfactory factor from households will be considered in residential loads management procedure. Loads will be shifted in order to avoid peak time period to off peak time while keeping the highest satisfactory score of users. The results show that after applying the procedure to 30 households in Tha Sala district, Nakhon Si Thammarat province, Thailand, overall price of electricity bills reduce at 2.17% with 95.6% satisfactory score by shifting only freely shiftable loads and the bills reduce at 6.22% with 87% satisfactory score by shifting all shiftable loads. It affirms that the procedure can be developed to be the algorithm for smart meters which will encourage households to attend the demand side management program as each household which has different lifestyles will be treated in their ways instead of using identical smart meter for all households having different ways of living.

Keywords: *Demand responsive management; energy efficiency; residential sector; algorithm for smart meter*

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1. Introduction

Currently, energy is one of the most considerable issues in the world since most of the present energy sources are nonrenewable which mainly from coal, oil, and natural gas (World Energy Council, 2013; Renewables Global Status Report, 2014). Although coal is the cheapest source of energy and will last for more than hundred years (World Energy Council, 2013; Renewables Global Status Report, 2014), it is harmful to the world environment; therefore, the number of countries having policies to reduce the use of coal as the main source of energy is exponentially increasing. Consequently, renewable Energy will be the future solution for energy crisis; however, electricity power systems and renewable technologies currently installed cannot contribute to the aim of the reduction rate of nonrenewable energy sources without cooperating with the demand responsive management system. Demand responsive management may contribute energy systems by balancing loads after partially shifting them from peak time out to off peak period. The Provincial Electricity Authority (PEA) of Thailand reveals load profile data in residential section of overall household in Thailand as shown in Fig. 1 informing that people highly use electricity between 6PM to 10PM. PEA has to invest in building power plants in order to support the peak value. Demand responsive management may reduce the peak value from shifting unnecessary loads to work out of the peak time. Electricity time of use and real time pricing are usually considered to make a response from households; notwithstanding, users' satisfactory level is rarely mentioned. In this paper, satisfactory level of users will be asked for each household in order to response to the system effectively in both aspects, pricing and satisfactory aspects of households.

2. Methodology

2.1 Data Collection

In order to comprehend electricity usage patterns in each specific area and acquire information about appliances being used locally, 30 households situated in Tha Sala district, Nakhon Si Thammarat province, Thailand were interviewed. The interviews were accompanied with questionnaires. Questions mainly asked for numbers, types, time of use, power of appliances in each household, and the most importantly, satisfactory levels of time if each appliances is shifted from the regular time of use.

2.2 Data Analysis

Satisfactory level is divided into 5 levels. Level 5 represented the time that each appliance is regularly used, level 4 represented the time to which users are insignificantly bothered from shifting each appliance from regular time of use, level 3 represented the time to that users are a little bit irritated but still acceptable to change the time of use of each appliance, level 2 represented the time that users are annoyed if each appliance is shifted to work at this period of time, and level 1 represented the time to which is not acceptable for users to shift each appliance.

According to Korkua and Thinsurat (2014), appliances in Tha Sala area can be separated into 9 types which are lighting devices, enjoyment, office appliances, kitchen appliances, refrigerators, space cooling devices, electronics charging devices, heating devices, and washing machines. In order to control the appliances, controllability of the appliances must be determined. In this paper, controllability of loads will be classified into four types; uncontrollable loads, uninterruptible loads which can be shifted with permission, interruptible loads that can be shifted with permission, and freely shiftable loads that can be shifted without any consumers' difficulty. For illustration, classification will be shown in Table 1.

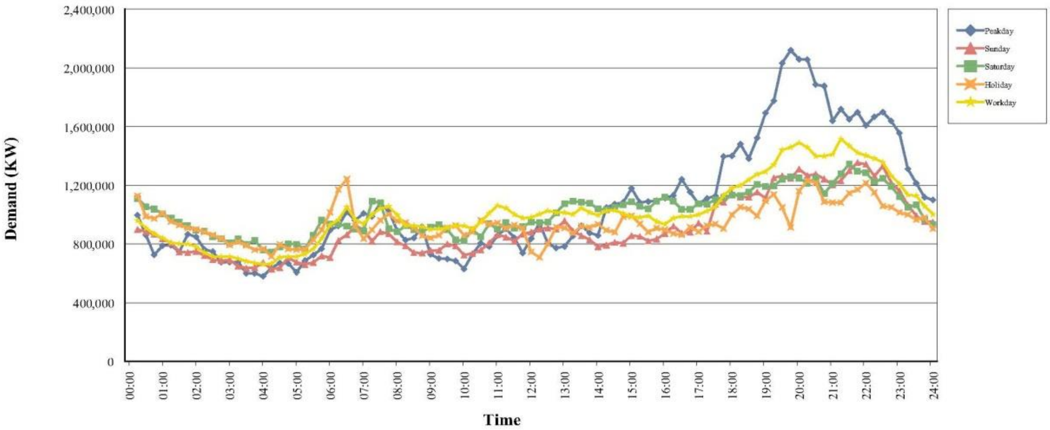

Fig. 1 Residential load profile in April 2014 of overall provincial households in Thailand from Provincial Electricity Authority (PEA) of Thailand.

Table 1 Loads Controllability

Loads	**Controllability levels**			
	Uncontrollable loads	Shiftable loads		
		uninterruptible loads	Interruptible loads	Freely shiftable loads
lighting devices				
enjoyment				
office appliances				
kitchen appliances				
Refrigerators				
space cooling devices				
Electronics charging devices				
Heating devices such as irons				
washing machines				

2.3 Loads shifting procedure

Loads will be shifted according to the controllability levels. Freely shiftable loads will firstly be shifted by considering the satisfactory levels. Thus, freely shiftable loads which are currently in satisfactory level 5 are going to be shifted to level 4 and if there is not enough time slots in level 4, then shifted to level 3 and so on respectively. However, some appliances are in uninterruptable type; for this reason, a program cannot split the time slots of operation of the appliances if the same satisfactory level is not adjoining. Instead, it will seek for adjoining time slots that make the highest satisfactory score after shifting. The other types of shiftable loads which are interruptible and uninterruptible loads will need a permission from users to allow the program to shift loads as it may affect regular lifestyle of the users. Nevertheless, they will get much lower price of electricity bills as a result as appliances in this type of controllability are in a high power consumption type.

2.4 Electricity bills calculation

In order to compare the electrical bills between using business as usual rates and time of use rates, the two systems in Thailand need to be demonstrated.

Business as usual is divided into two types; the first one is for households using the electrical energy less than 150 units (kWhr) and the other one is for the households using more than 150 units of energy. Rates of these two types are illustrated in Table 2.

Table 2 Business as usual electricity rates

Type 1: For the household regularly* using less than 150 units (kWhr)		
First 15 units	1-15 units	1.8632 bahts per unit
Next 10 units	16-25 units	2.5026 bahts per unit
Next 10 units	26-35 units	2.7549 bahts per unit
Next 65 units	36-100 units	3.1381 bahts per unit
Next 50 units	101-150 units	3.2315 bahts per unit
Next 250 units	151-400 units	3.7362 bahts per unit
More than 400 units	401 units onward	3.9361 bahts per unit
Type 2: For the household regularly using more than 150 units (kWhr)**		
First 150 units	0-150 units	2.7628 bahts per unit
Next 250 units	151-400 units	3.7362 bahts per unit
More than 400 units	401 units onward	3.9361 bahts per unit

* If electricity energy is consecutively used more than 150 units for 3 months, the household will be considered to be type 2.

** If electricity energy is consecutively used less than 150 units for 3 months, the household will be considered to be type 1.

For time of use rates in Thailand, there are just only two ranges of prizing related to the time of using. Peak time is considered to be on Monday through Friday from 09.00AM until 10.00PM and off peak time is from 10.00PM at night through 09.00AM in the morning including 24-hour on weekend and holidays. The prize for peak time is 5.2674 baht per unit (kWhr) and 2.1827 baht per unit (kWhr) for off peak time.

For comparison, business as usual bills from each sample households were collected for one year then calculated the average per month. Interviews were used to inform the number of hours of each appliance used per day and the number of days per month. Calculations of an electricity bill from each household were made from interviewed information in order to accurately attain the used hours and days of each appliance for 30 households by comparing to the real electricity bills collected from each household. By doing the aforementioned process, the used hours per day and used days per month are precisely stated and can be used for calculation in time of use rates.

3. Results and discussion

After shifting the freely shiftable appliances from all 30 households, the total price of electricity bills reduces from 16,283 Bahts to 15,929 Bahts which is 2.17% reduction with 95.6% satisfactory score and after shifting all shiftable loads, the price reduces to 15,271 Bahts which is 6.22% reduction with 87% satisfactory score. The loads' pattern is changed according to the shifting procedure as shown in Fig. 2.

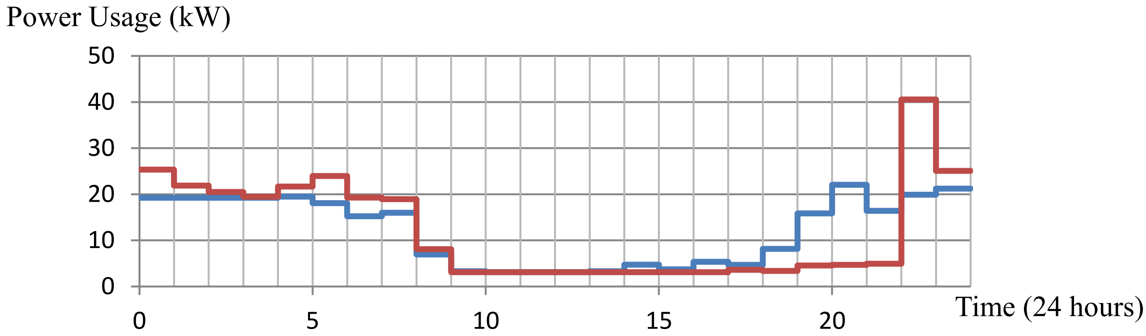

Fig. 2 Loads' pattern from over all 30 households; x-axis is the time (24 hours) and y-axis is power consumption; the blue line and the red line show the loads' pattern before and after loads shifting respectively.

Notice that, the average power consumption over 24-hour period does not change after shifting; therefore, the overall energy usage remains the same. There is just only 1 household out of 30 samples which the TOU bill is exactly the same as the BAU bill because the members of the household do not spend time at home during peak time period. The other 29 households get profit from using the proposed procedure as the electricity bills are reduced by using TOU rates combined with load shifting procedure. Electricity bills significantly reduced in households which mainly spend time during peak time period.

With the fact that the sample households are from the same community where members of these households have similar lifestyles, the results cannot be used to represent the whole system of residential sector in Thailand. However, the lifestyles of sample members, for example working at daytime and going home at night, are currently norm. Those people spend most of the time at home in off peak period where the electricity prize is low. It can be implied that, if the proposed procedure is used with households that members spend most of the time in peak period, the percent reduction of electricity bill may increase compared to the results in this paper.

Moreover, it is obvious that, technologies in the near future will depend themselves on electricity instead of fossil fuels; therefore, balancing electrical loads over time with the proposed procedure by considering households' satisfactory levels of each electrical loads would be a solution idea as each household has different preferable time of using each electrical loads.

The proposed idea of considering households' satisfactory levels of each appliance is to support the algorithm for smart meters which are the device for monitoring and controlling electrical loads in households. To be smart, smart meters should not work in the same manner for different households as members in different households may prefer using each appliance in different time. Therefore, smart meters should ask for preferable time of each appliance before shifting them to work in the new period of time.

In the future, satisfactory scales may be adjusted in order to represent the real feeling of satisfaction. In this paper, satisfactory scales are divided into 5 levels from 5 to 1. However, it may be too rough to classify the satisfactory levels into 5 levels. It may be more precise to use percent satisfactory level instead. Furthermore, time should be discretized into minute unit instead of 1 hour in order to get better result.

4. Conclusion

Demand side management can reduce the peak value by shifting loads out of peak time; however, loads are usually shifted out in order to make the lowest price of electricity bills without considering household preferable time. This paper shows that, it is possible to keep the concept of shifting loads out of peak time along with optimization to get the highest satisfactory score from members of sample households. Thirty sample households were interviewed for preferable time of use of each appliance. Five satisfactory levels are used in order to classify the time of loads shifting. After following the procedure mentioned in prior sections, the results show that overall price of electricity bills reduce from 16,283 Bahts to 15,929 Bahts which is 2.17% reduction with 95.6% satisfactory score for shifting only freely shiftable loads and after shifting all shiftable loads, the price reduces to 15,271 Bahts which is 6.22% reduction with 87% satisfactory score using 30 households sample in Tha Sala district, Nakhon Si Thammarat province, Thailand. It ensures that the algorithm can be applied to smart meters for controlling loads in residential sector which each household has different lifestyles instead of using identity smart meter for all households having different ways of living.

5. References

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