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The Novel Price Elasticity of Demand Model for Time of Use Electricity Rates Determination

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Abstract

Nowadays, people pay attention to renewable energy due to its clean energy and decrease of fossil fuels reliance. Solar energy which is a part of renewable energy plays an important role in electricity generation because of its reasonable cost of devices and convenient to install at building and rooftop. This is the cause of electricity generation increasing in the daytime. While the power demand in the residential customer in the night time keep on going up but low power demand at daytime. The electricity rates determination is important part in order to persuade customer to changed their behavior of electric consumption. The time-of-use (TOU) rates which determines different electricity price rate for different time period in a day is extensively applied to electrical system for encouraging customer participation in demand response program. This paper presents the method to determine optimal TOU rates for residential customer by using price elasticity of demand model to evaluate the change in demand after changing electricity rates. The new cross-elasticity is proposed in order to determine power demand change due to change of electricity rates at other times. TOU rates determination has three objectives consisting of minimizing peak demand, maximizing load factor (L.F.) and minimizing customer's energy cost which benefit both utility and customers. To find the optimal value of TOU rates, Multi-Objective Differential Evolution (MODE) is used to solve problem and show the Pareto front of non-dominated solution. The proposed method is applied to residential customers of provincial electricity authority (PEA). The result of new optimal TOU evaluation shown that peak load and total customer's energy cost were decreased and load factor was increased from the original data.

Keywords: Multi-Objective Differential Evolution (MODE), Pareto front, power demand, price elasticity of demand (PED) and time-of-use (TOU) rates

I. INTRODUCTION

At present, renewable energy gets a lot of attention because it is unlimited clean energy and it reduces the dependence of fossil fuel. Solar energy is the most popular one of the renewable energies because it has reasonable cost of devices and it is convenient to be installed even at rooftop of household. However, solar photovoltaic (PV) can generate electricity only in daytime while power demand still grows up especially in night time. Example in California, large capacity of PV is installed which leads load profile shape to duck curve [1]. Unless technical energy management by use of energy storage, the price-based demand response program also be applied to change behavior of customer energy consumption. The TOU rates is electricity pricing for each time period in order to reduce peak demand by convincing customer to change their energy consumption behavior [2]. The result of decreasing peak demand is supposed to reduce the investment infrastructure costs. In China, TOU rates is defined to motivate the customers to change their energy consumption behavior. The purpose is to reduce customer electricity cost and system peak load. The numerical simulation is used to solve problem by optimizing many-objective function composing of minimizing customer electricity cost and maximizing load shifting. The TOU rates consist of off-peak, mid-peak and peak rates based on typical load data. The result of evaluation shows that the optimal TOU rates can motivate customer to shift their consumption from peak load to off-peak load and decrease customer electricity expenditure [3,4,5]. There are many studies of clustering algorithm that used to classify load curve characteristic by seasonal. After that, the price demand elasticity coefficient is applied to model the TOU rates for each typical load. The load curve evaluation after implementing the optimal TOU rates shows that an incentive price can persuade the customers to change the energy consumption behavior following objectives consisting of minimizing peak and valley load and minimizing user's electricity cost. Nevertheless, the load is still high in some period [6]. In Cyprus, the approach to determine the optimal TOU rates for residential prosumers is presented. The purpose is minimizing electricity cost of prosumers and load factor (LF). The obtained TOU rates were applied to three hundred prosumers which can decrease the peak demand by shifting the prosumers consumption behavior from peak period to off-peak period [7]. In Denmark, there are studies in optimal TOU rates to decrease total electric consumption cost of commercial, residential and industrial customers. The constraints taken into consideration consist of the equal of total energy consumption before and after using the optimal TOU rates and the limitation of power demand change of each period is not more than 20% of initial power demand. The result of three customer types shows significantly reduce the system peak load after using optimal TOU rates by sequential quadratic programming optimization [8]. In Iran, there are the studies on demand response program which change electricity rate from flat rate to TOU rate. The purpose of using optimal TOU rates is to increase benefits of customer and utility that cause peak demand decrease. The single period (self-elasticity) and multi period (self and cross elasticity) are defined in scenario for considering the change of demand [9]. Most of optimal TOU problems have many objectives to be solved which benefit both customer and utility. From previous studies, most studies used the weighted sum approach to combine many objectives to be single objective and then basic algorithm such as linear programming and sequential programming is used to solve problem. Over the years, the meta-heuristic algorithms which imitate a nature system evolutionary have been developed to solve problem. Other than genetics algorithm (GA) which is most popular, Differential Evolution (DE) algorithm is famous optimization because it has a very strong global search capacity [10] with a simple procedure. Furthermore, Differential Evolution (DE) was developed to solve many objectives problem called Multi-Objective Differential Evolution (MODE) [11]. The solution from MODE is the set of Pareto-optimal solution (Pareto front) which obtained from non-dominated sorting process in a single run [12,13].

Hence, this article proposes a method to determine the optimal TOU rates which objectives are decreasing the peak power demand, total customer's energy cost and increasing load factor (L.F.). The constraints for this problem include peak power demand limit, load factor limit, the proportion between peak and off-peak price and the total customer's energy cost limit. The behavioral changes in electricity consumption after the change in prices adopt economic elasticity demand price model to demonstrate the change in power demand. For the optimization algorithm, the Multi-Objective Differential Evolution (MODE) is adopted to find the set of Pareto-optimal TOU rates.

II. METHODOLOGY

II.I TOU demand response

TOU is one of the time-based rate of demand response programs which extensively used to convince customers to change their energy consumption behavior. TOU determine different prices at different times. On peak demand period will have a higher electricity price than off-peak demand period.

Separation rates of TOU depend on power demand level and TOU rates in each period is normally divided into 2-3 rates in a day. Therefore, the TOU time periods will be written as equation (1).

$$T_{O-Pk} + T_{M-Pk} + T_{Pk} = 24 \tag{1}$$

where, $T_{O-Pk}, T_{M-Pk}, T_{Pk}$ are the total time (hour) in off-peak period, mid-peak period and peak period, respectively.

The energy can be derived from the power demand of each period of time. The summation of power demand in each TOU periods is the total energy consumption that can be expressed as equation (2).

$$\begin{aligned} EN &= \int D(t)dt = \int_{T_{O-Pk}} D(t)dt + \int_{T_{M-Pk}} D(t)dt + \int_{T_{Pk}} D(t)dt \\ &= EN_{O-Pk} + EN_{M-Pk} + EN_{Pk} \end{aligned} \tag{2}$$

where EN is the sum of energy consumption (kWh) in a day. $D(t)$ is defined as the power demand (MW) in the time t in a day. EN_{O-Pk}, EN_{M-Pk}, EN_{Pk} are the sum of energy consumption (kWh) in off-peak periods, mid-peak period and peak period, respectively.

II.II Economic demand response model

In economic term, the price elasticity of demand (PED) is applied to express the proportion of the percent change of demand and percent change of price which can be shown as equation (3).

$$\varepsilon_D = \frac{\frac{\Delta D}{D_O} \times 100}{\frac{\Delta P}{P_O} \times 100} = \frac{\Delta D}{\Delta P} \times \frac{P_O}{D_O} \tag{3}$$

where the PED is denoted as ε_D. D_O is the original demand and P_O is the original price (USD), respectively. ΔD and ΔP are the demand and price (USD) changed from the originals, respectively

The PED composes of self-price elasticity of demand (SPED) and cross-price elasticity of demands (CPED) which can be described as below.

1) Self-price elasticity of demand (SPED) is the ratio of the change in power demand and the change in electricity price at the time t . normally, if the price rises up, demand will decrease. The relationship between price and demand is contrary. Therefore, SPED is lower than zero that can be expressed as equation (4).

$$\varepsilon_D(t,t) = \frac{\Delta D(t)}{\Delta P(t)} \times \frac{P_O(t)}{D_O(t)} \leq 0 \tag{4}$$

where $\varepsilon_D(t,t)$ is the SPED at the time t . $D_O(t)$ and $P_O(t)$ are the original demand (kW) and the original price (USD) at the time t , respectively. $\Delta D(t)$ and $\Delta P(t)$ are the change of demand (kW) and the change of price (USD) at the time t , respectively.

Therefore, the power demand that changes from the original demand after price change can be rewritten from equation (4) as shown in equation (5).

$$D(t) = D_O(t) + \varepsilon_D(t,t) * D_O(t) \left[\frac{P(t) - P_O(t)}{P_O(t)} \right] \tag{5}$$

where $D(t)$ is the power demand (kW) at the time t . $P(t)$ is the new electricity price (USD) at the time t that changes from the original price.

2) Cross-price elasticity of demand (CPED) is the proportion of the change in demand of considered product at the time t and the change in price of the other products or the other times. The demand of considered product is increased after the price of the other products or other times increases that can be called two products are substitute for each other. Thus, the demand of considered product directly varies as the price of the other products or other times. Generally, the CPED is higher than zero that can be written as equation (6).

$$\varepsilon_D(t,u) = \frac{\Delta D(t)}{\Delta P(u)} \times \frac{P_O(u)}{D_O(t)} \geq 0 \tag{6}$$

In electrical term, the change in power demand from the original demand at the time t is influenced by the change in electricity price of other times in 24 hours which can be expressed as equation (7).

$$D(t) = D_O(t) + D_O(t)\sum_{u=1,t\neq u}^{24} \varepsilon_D(t,u)\left[\frac{P(u)-P_O(u)}{P_O(u)}\right] \tag{7}$$

Therefore, the total change in power demand from the original power demand at the time t is derived from the SPED and CPED after changing prices in 24 hours which can be written as equation (8).

$$D(t) = D_O(t)\left\{\begin{array}{l} 1+\varepsilon_D(t,t)\left[\dfrac{P(t)-P_O(t)}{P_O(t)}\right] \\ +\displaystyle\sum_{u=1,t\neq j}^{24} \varepsilon_D(t,u)\left[\dfrac{P(j)-P_O(u)}{P_O(u)}\right] \end{array}\right\} \tag{8}$$

II.III Multi-Objective Differential Evolution (MODE) optimization

The optimal designed variables from the problem which has many objectives can be obtained from multi-objective optimization. The obtained result shows the set of optimal solution that compromises among many objectives. The optimal solution set is called Pareto front. MODE is a meta-heuristic optimization algorithm that based on differential evolution. Differential evolution is the most popular algorithm because it is simple to use with a few parameters to search global optimal value. Normally, Multi-objective optimization can be written in mathematical formulation as shown below.

Maximize/Minimize

$$\mathrm{f} = \{ f_1(\mathbf{x}),..., f_n(\mathbf{x})\} \tag{9}$$

Subject to

$$g_i(\mathbf{x}) \leq 0 \tag{10}$$

$$h_i(\mathbf{x}) \leq 0 \tag{11}$$

$$\mathbf{x}_L \leq \mathbf{x} \leq \mathbf{x}_U \tag{12}$$

where $\mathbf{x}$ is a design variable vector which $\mathbf{x}_L, \mathbf{x}_U$ are lower and upper bounds, respectively. $f_n(\mathbf{x})$ is the objective function. n is the number of objective functions, $g_i(\mathbf{x})$ is inequality constraints and $h_i(\mathbf{x})$ is equality constraint. i is the number of constraints.

II.III.I Mutation process

After generating initial population which is randomized within lower and upper bounds, mutation process generates a mutant vector by randomly chosen dissimilar vector as shown below.

$$\mathbf{u}_i = \mathbf{x}_{i1} + \mathrm{F} * (\mathbf{x}_{i2} - \mathbf{x}_{i3}) \tag{13}$$

where $\mathrm{F} \in [0,1]$ is a scaling factor. u_i is the mutant vector from mutation process. $\mathbf{x}_{i1}$ is vector which is randomly selected from non-dominated solution. $\mathbf{x}_{i2}$ and $\mathbf{x}_{i3}$ are randomly selected vector where $\mathbf{x}_{i2} \neq \mathbf{x}_{i3}$.

II.III.II Crossover process

In the crossover process, the mutant generated vector $(\mathbf{u}_i)$ and the parent vector $(\mathbf{x}_i)$ are recombined by using binary crossover. A random number (rand) is created between [0,1] and then it is compared with the selected crossover ratio (C_R).The element *j*-th of the trial vector $(\mathbf{v}_i)$ from crossover process can be written as shown below.

$$v_{i,j} = \begin{cases} u_{i,j}; \text{if rand} \leq C_R \\ x_{i,j}; \text{if rand} > C_R \end{cases} \tag{14}$$

where $C_R \in [0,1]$ is the selected crossover ratio.

II.III.III Selection process

After the mutation and crossover process, the non-dominated sorting is adopted to sort the union population of the trial vector and the Pareto front set. Then the non-dominated solutions are updated to use in the next iteration.

II.III.IV Non-dominated sorting

In this process, the Pareto front set that is the set of non-dominated solutions can be obtained by the optimality conditions as follows. The $\mathbf{x}_1, \mathbf{x}_2$ are design variables and $f_i(\mathbf{x})$ is objective function where $i=1,...,n$ If $f_i(\mathbf{x}_1) \leq f_i(\mathbf{x}_2)$ *for all index* $i \in \{1,..., p\}$ and there is at least one index j in $\{1,... ,p\}$ which $f_j(\mathbf{x}_1) < f_j(\mathbf{x}_2)$. It can be said that $\mathbf{x}_1$ dominates $\mathbf{x}_2$.

III. PROPOSED PROBLEM FORMULATION

III. I Proposed New Cross-Elasticity

From CPED as descripted in section 2.2, the power demand at considered time varies directly with the change in price at other times as there are substitute products or services. However, the change in price at the other times will not affect to the change in power demand at the considered time when the below conditions are occurred.

Table 1. the proposed new cross-elasticity

			Other times					
			Off-peak to Off-peak	Off-peak to Mid-peak	Off-peak to Peak	Peak to Off-peak	Peak to Mid-peak	Peak to Peak
			Decrease	Increase	Increase	Decrease	Decrease	Increase
consider current time	Off-peak to Off-peak	Decrease	0	1	1	1	0	1
	Off-peak to Mid-peak	Increase	1	0	1	1	1	1
	Off-peak to Peak	Increase	1	0	0	1	1	0
	Peak to Off-peak	Decrease	0	1	1	0	0	1
	Peak to Mid-peak	Decrease	1	0	1	1	0	1
	Peak to Peak	Increase	1	0	0	1	1	0

where, 1 means enable to use $\varepsilon_D(t,u)$.

1) If the change in price at the other times is equal to the change in price at the considered time and the new TOU prices of them are equal, then the change in price at the other times will not impact to power demand at the considered time.
2) If the change in price at the other times increases as same as the change in price at considered time and the new TOU price at the other times is lower than the new TOU price at the considered time, then the change in price at the other times will not affect to power demand at the considered time.
3) If the change in price at the other times increases as same as the change in price at considered time and the new TOU price at the other times is equal to the new TOU price at the considered time, then the change in price at the other times will not affect to power demand at the considered time.
4) If the change in price at the other time decreases as same as the change in price at considered time and the new TOU price at the other times is higher than the new TOU price at the considered time, then the change in price at the other times will not affect to power demand at the considered time.

III.II Objective function

TOU rates are applied in the electricity market to persuade customers to change their electric energy consumption more efficiently. The utility and the customers will get benefit together after TOU implementation. Minimizing peak demand can help the utility to decrease electricity generation from high cost fuel and postpone investment in power plant. Maximizing load factor can help utility to decrease variation in electrical system. Minimizing total customer's energy cost can help the utility and the customers to decrease the expense. Thus, the objective function can be expressed as follows.

1) To minimize the peak demand.

$$Min\left\{D(t, P_{N\_Off-Pk}, P_{N\_Mid-Pk,}, P_{N\_Pk})\right\} \tag{15}$$

where $P_{N\_Off-Pk}, P_{N\_Mid-Pk,}, P_{N\_Pk}$ are electricity prices in the off-peak period, mid-peak period and peak period after implementing a new TOU rates (USD/kWh), respectively.

2) To maximize the load factor

$$Max\left\{\frac{Average\left\{D(t, p_{N\_Off-Pk}, p_{N\_Mid-Pk,}, p_{N\_Pk})\right\}}{Max\left\{D(t, p_{N\_Off-Pk}, p_{N\_Mid-Pk,}, p_{N\_Pk})\right\}}\right\} \tag{16}$$

3) To minimize the total customer's energy cost.

$$\begin{aligned} TotalP_N &= EN_{N\_Off-Pk} * P_{N\_Off-Pk} + \\ & EN_{N\_Mid-Pk} * P_{N\_Mid-Pk} + EN_{N\_Pk} * P_{N\_Pk} \end{aligned} \tag{17}$$

where $TotalP_N$ is the total customer's energy cost after implementing a new TOU rates (USD/kWh). $E_{N\_Off-Pk}, E_{N\_Mid-Pk}, E_{N\_Pk}$ are the new total energy consumption (kWh) in the off-peak period, mid-peak period and peak period after implementing a new TOU rates, respectively.

III.II Constraints

The new TOU rates determination has the constraints which TOU rates has to conform for obtaining reasonable TOU rates in each period. The constraints consist of the following as shown below.

III.II.I Inequality constraints

1) The new peak demand has to be lower than the original peak demand.

$$Max\left\{D(t,P_{N\_Off-Pk},P_{N\_Mid-Pk},,P_{N\_Pk})\right\} \leq Max\left\{D_O(t,P_{O\_Off-Pk},P_{O\_Pk})\right\} \quad (18)$$

where p_{O_Off-Pk}, p_{O_Pk} are the electricity prices of original TOU rates in the off-peak period and peak period (USD/kWh), respectively.

2) The new load factor has to be higher than the original load factor.

$$LF_N\left\{D(t,P_{N\_Off-Pk},P_{N\_Mid-Pk},,P_{N\_Pk})\right\} \geq LF_O\left\{D_O(t,P_{O\_Off-Pk},p_{O\_Pk})\right\} \quad (19)$$

where LF_N is the load factor after using a new TOU rates and LF_O is the load factor using original TOU rates.

3) The difference limited of the price in peak period and off-peak period should be determined in order to avoid the price in peak periods lower than the price in off-peak periods.

$$2 < \frac{P_{N\_Pk}}{P_{N\_Off-Pk}} < 4 \quad (20)$$

4) The price in new mid-peak period is higher than the original average price.

$$P_{N\_Mid-Pk} \geq p_{O\_avg} \quad (21)$$

where p_{O_avg} is the average electricity prices using an original TOU rates (USD/kWh).

5) The total customer's energy cost that uses a new optimal TOU rates is lower than the original total customer's energy cost to convince customers to change their energy consumption from peak period to the others period.

$$TotalP_N \leq TotalP_O \quad (22)$$

where $TotalP_O$ is the original total customer's energy cost (USD).

III.II.II Equality constraints

1) The total energy that uses a new optimal TOU rates is equal to the total energy that uses an original TOU rates.

$$ENTotal_N = ENTotal_O \quad (23)$$

where $ENTotal_N, ENTotal_O$ are the original total energy using an original TOU rates (kWh) and the new total energy using a new TOU rates (kWh), respectively.

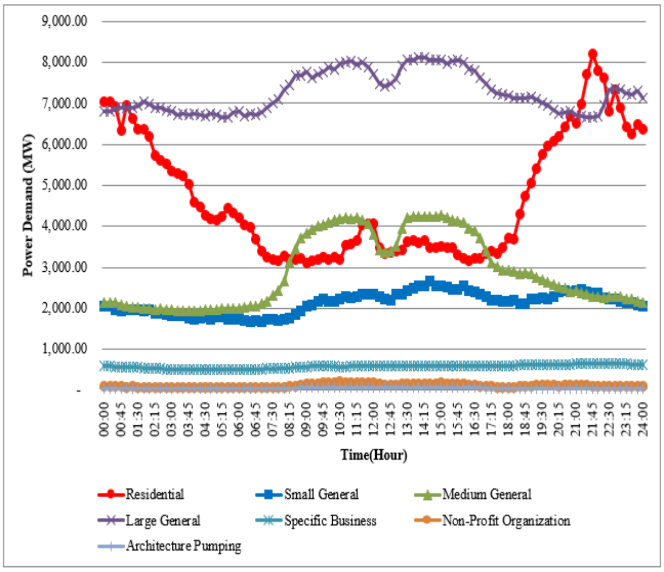


Fig.1 The power demand of PEA, Thailand on a peak day in 2017 classified by the types of customers

IV. RESULT AND DISCUSSION

IV.I Data parameter before using a new TOU rates

In 2015, an alternative energy development plan (AEDP) of Thailand purposes to rise the proportion of renewable energy usage for electricity generation to 18% of total fuel used for electricity generation within 2036 [14]. For energy consumption, load research data of provincial electricity authority (PEA) of Thailand [15] that records the power demand every 15 minutes in a day show the peak power demand occurring on Wednesday 3rd May 2017 at 21:45. The highest peak power demand is 20,328 MW that mostly comes from residential customers.

Furthermore, the difference between peak and off-peak demands of the residential customer is higher than the difference of other customer types that means residential customer has the highest load factor. Since 2000, TOU has been used in residential customer that has two rates and two periods until present as shown in Table 2. However, the power demand of residential customer at the current situation changes from the past which has longer periods of the peak power demand at night and the power demand at day time decreases because of the supply from renewable energy generation especially, solar photovoltaic. In order to adjust TOU rates to be suitable for present situation, the residential customer is brought to evaluate the new TOU rates.

Table 2. The original TOU rates for residential customer [16].

Period	Time(hour)	Price (USD/kWh)
Peak	09:00-22:00	0.18675
Off-Peak	22:00-24:00	0.08493

Table 3. The new TOU period for residential customer.

New period	Time (hour)
Peak	00:00-02:00, 20:00-24:00
Mid-Peak	02:00-06:00, 18:00-20:00
Off-Peak	06:00-18:00

Normally, the TOU rates in many counties were determined for two to three rates that depend on the power demand profile. From the observed power demand of residential customer in Fig.1, it can be noticed that the power demand has three levels. There are the low power demand level which is set as off-peak period, the high power demand level which is set as peak period and the power demand level between low and high power demand which is set as the mid-peak period as shown in Table 3.

Electricity plays an essential role in residential customers living. In spite of high electricity price, residential customers still use electricity. In May 2015, the demand response programs have been implemented as the pilot project for industrial customers who are disposed. The self-elasticity and cross-elasticity from the pilot project data are -0.272 and 0.16, respectively [17]. Most of demand response programs that study on residential customers use self-elasticity and cross-elasticity equal to -0.1 and 0.008-0.01, respectively [6,7,9]. Because the power demand change of residential customer's behaviour is more difficult than the power demand change of industrial customer's behaviour, this study defines the self and cross-elasticity at the lowest values as shown in Table 4.

IV.II Simulation result

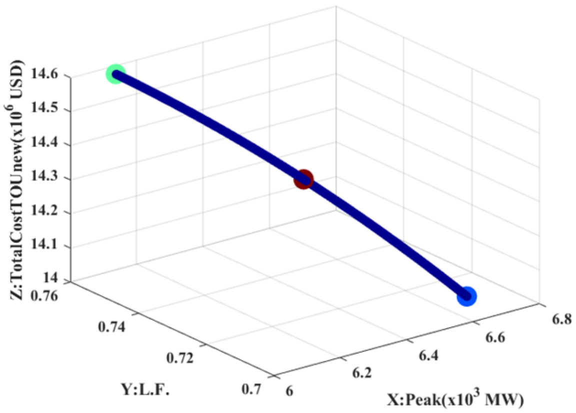
The result of new TOU evaluation which changes TOU rates from 2 to 3 rates after using MODE to find the optimal rates and elasticity price model with 3 objectives subject to the constraints can be described as the following.

The Pareto front of three objectives after using MODE shows in Fig.2 The extreme point of minimizing peak load value represent green color point and this point is the extreme point of maximizing L.F. value also but has the highest total customer's energy cost. The extreme point of minimizing total customer's energy cost value represent blue color point which has lowest total customer's energy cost but has lowest L.F. value and highest peak load value. The middle of all objectives is shown as brown color.

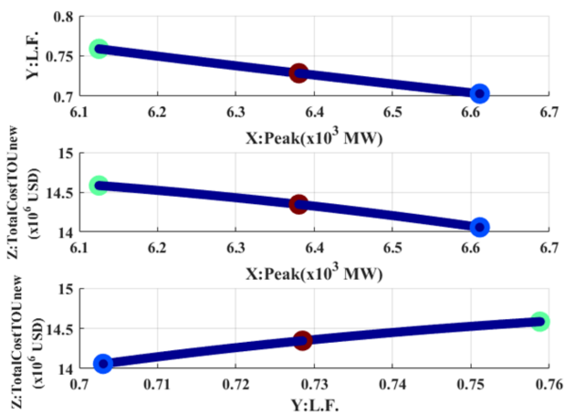
Table 4. The price elasticity of electricity demand

	SPED	CPED
PED	-0.1	0.008

For the correlation among the values of peak load, L.F. and total customer's energy cost, the relation between peak load and L.F. shows an inverse variation which decreasing peak load is the cause of increasing L.F.



(a)



(b)

Fig. 2. The Pareto front of three objectives after using MODE (a) The Pareto front plotted in three dimensions (b) The Pareto front comparison in two dimensions

The relation between peak load and total customer's energy cost also shows an inverse variation which must use high price to reduce peak load then total customer's energy cost is high at low peak load. Whereas, the relation between L.F. and total customer's energy cost is direct variation. The feasible region of the minimizing peak is about 6.105-6.625(x10^3 MW), the maximizing L.F. is about 0.7-0.76 and minimizing total customer's energy cost is 14.0-14.6(x10^6 USD).

The optimal TOU rates after using MODE is shown in Fig.3 Conversely, the extreme point of minimizing peak load is the green color point which provides the lowest off-peak and peak prices but provides the highest mid-peak price. The extreme point of minimizing total customer's energy cost is the blue color point which provides the highest off-peak and peak prices but provides the lowest mid-peak price. The feasible region of the off-peak price is about 0.0575-0.063 (USD/kWh) while, the

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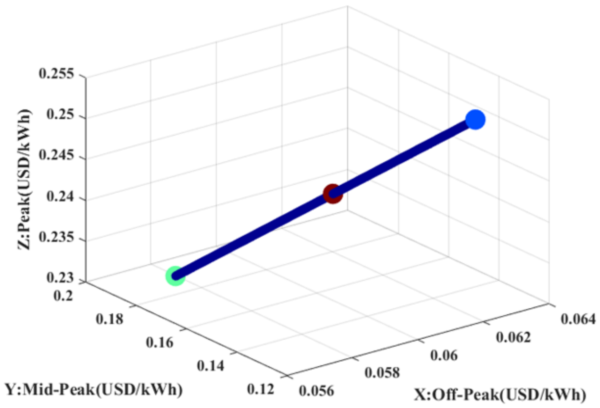
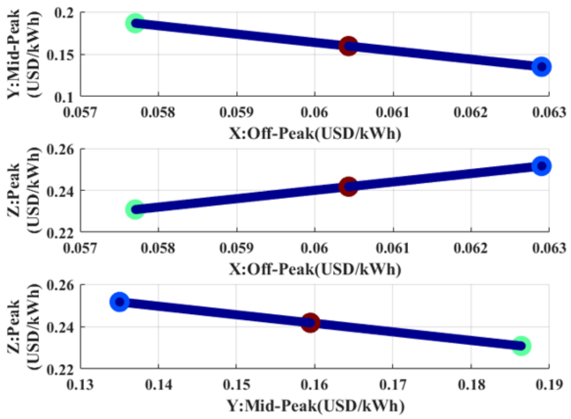
mid-peak price is about 0.135-0.19 (USD/kWh) and peak price is 0.230-0.255 (USD/kWh).



(a)



(b)

Fig. 3. The optimal TOU rates after using MODE (a) The optimal TOU rates plotted in three dimensions (b) The optimal TOU rates comparison in two dimensions

Fig. 4 shows the power demand after using optimal TOU rates considering each objective. The highest change of price is 22:00-02:00 period which changes the price from original off-peak period to peak period. The result shows a significant decrease in power demand. Conversely, during 09:00-18:00 period, a significant decrease of price from peak to off-peak causes the significant increase in power demand because the customers change their consumption based on electricity price. Consequently, the increased power demand in this period can conform to the government policy to increase the generation of solar photovoltaic (PV) which generates power at daytime. While, during 20:00-22:00 period is still determined as peak period but the price is increased that causes the power demand decrease. During 02:00-09:00 and 18:00-20:00, the slightly change of price affects a little change in demand.

From Table 5., the highest percentage decrease of the total customer's energy cost is 6.68% comparing with the original total customer's energy cost. This comes from the extreme point when considering minimizing total customer's energy cost as the main objective. The highest percentage decrease of the peak load is 25.34% comparing with the original peak load. This comes from the extreme point when considering minimizing peak load as the main objective.

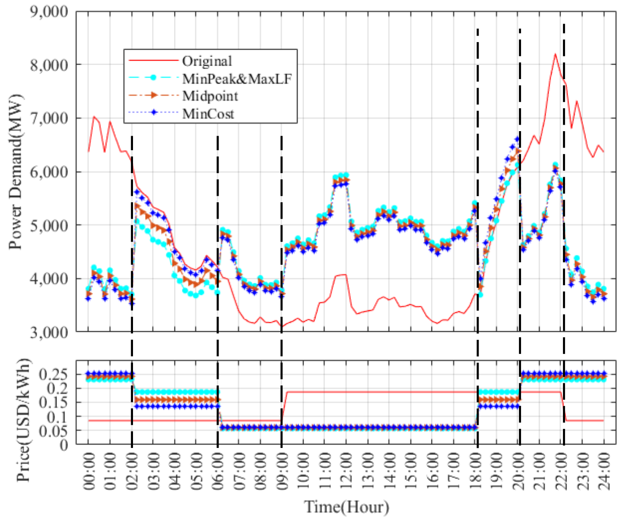


Fig. 4. The power demand profiles after using optimal TOU rates considering each objective

Moreover, at the same position, it provides the highest percentage increase of load factor about 33.95% comparing with the original load factor. All optimal values do not violate any constraints that previously mentioned**.**

V. CONCLUSION

This study presents the TOU rates determination method which changes the TOU rates from original two rates to three rates. The three new TOU rates are separated according to present power demand characteristic which has three power demand levels (off-peak demand, mid-peak demand and peak demand). The evaluation of change in power demand uses price elasticity of demand model which explain the effect of changed price to power demand. The new cross-elasticity is proposed in this paper which can help to evaluate the effect of demand change because the price of the other times change. The MODE is employed to evaluate these three new TOU rates with the three objectives consisting of minimizing peak demand, maximizing load factor (L.F.) and minimizing customer's energy cost. The set of three mutual objectives solution is shown as the Pareto front which is non-dominated solution. The correlation among three objectives shows that the peak load inversely varies with the load factor (L.F.) and the customer's energy cost. The high change in price will affect the high change in power demand as shown in 20:00-2:00 and 9:00-18:00 periods. The evaluation result shows the change of power demand after the price changes which is beneath multi-objectives and constraints. The result can be used as the information for decision making before implementation in power grid. All of optimal TOU rates in the Pareto optimal set from the evaluation can decrease peak load and customer's energy cost and increase L.F. which are better than using original TOU rate.

Table 5. Comparison of the evaluation values before and after using the optimal TOU rates

Evaluation values	Original TOU rates	Optimal TOU rates			%difference		
		Min (Peak) &Max (L.F.)	Mid-Point	Min (Cost)	Min (Peak) &Max (L.F.)	Mid-Point	Min (Cost)
Customer's energy cost (×10^6 USD)	15.0642	14.5830	14.3455	14.0577	-3.19%	-4.77%	-6.68%
Peak rate (USD/kWh)	0.1868	0.2308	0.2417	0.2516	23.60%	29.44%	34.72%
Mid-peak rate (USD/kWh)	-	0.1864	0.1594	0.1350	-	-	-
Off-peak rate (USD/kWh)	0.0849	0.0577	0.0604	0.0629	-32.06%	-28.84%	-25.94%
Peak rate/ Off-peak rate	2.1989	3.9999	4.0000	3.9999	81.91%	81.91%	81.91%
Maximum power demand (×10^3 MW)	8.2050	6.1250	6.3803	6.6112	-25.35%	-22.24%	-19.42%
Minimum power demand (×10^3 MW)	3.0932	3.6824	3.6142	3.5313	19.05%	16.84%	14.16%
Load factor	0.5665	0.7589	0.7285	0.7031	33.96%	28.60%	24.11%
Total energy consumption (×10^3 MWh)	111.5531	111.5531	111.5531	111.5531	0.00%	0.00%	0.00%

*Note: - means it cannot be evaluated due to mid-peak rate is have in the original TOU rates.

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