A novel PV size selection for time of use tariff for residence in Phayao province, Thailand

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Abstract

This research aims to study the photovoltaic (PV) size for residence that consider to take an advantage from the electricity cost of time of use (TOU) tariff. The study is conducted by considering the 2015 tariff rate of Provincial Electricity Authority (PEA). The research is studied only residence with electricity consumption over 150 kWh per month and at voltage level lower than 22 kV. In the study, the electricity generated from PV is used in peak time periods only. As the simulation results, the minimum and maximum PV size selection chart is demonstrated. The minimum and maximum PV size depend on the total electricity consumption before PV installation ($kWh_{T,E}$) and the existing ratio of electricity consumption in peak time (α_E). If the electricity consumption per month and the ratio of electricity consumption in α_E are increasingly high, the maximum size of the PV installation will be accordingly enlarged as well. In addition, the results showed that the customers who use the total electricity consumption less than 500 units per month and the ratio of electricity consumption in peak time more than 0.8 will not benefit to the TOU tariff.

Keyword:

Photovoltaic, time of use tariff, residence, peak time

Nomenclature

a	Constant
EC_N	Electricity cost of normal tariff (Baht)
EC_{TOU}	Electricity cost of TOU tariff (Baht)
kWh_{Peak}	Electricity consumption in peak time (kWh)
kWh_{PV}	Electricity energy was generated by photovoltaic (kWh)
$kWh_{T,E}$	Total electricity consumption before PV installation (kWh)
$kWh_{T,NE}$	Total electricity consumption after PV installation (kWh)
kWh_T	Total electricity consumption from PEA. (kWh)
PV	Size of photovoltaic (kW_P)
UR_N	Unit rate of normal tariff (Baht/kWh)
UR_{TOU}	Unit rate of TOU tariff (Baht/kWh)
α	The ratio of electricity consumption in peak time

Subscript

E	Existing
N	Normal tariff
NE	New

Peak	Peak Time Period
T	Total
TOU	Time of Use tariff
PV	Photovoltaic

1. Introduction

Smart Grid Technology is the development of the electrical system which can respond more intelligently. It is capable of using less resources, working effectively, sustaining resources, safety and environmentally friendly. This technology can be described as self-sufficient systems which can quickly solve problems in an available system reducing the resource and target sustainability. The energy management technology consists of the main grid of electricity, the renewable energy, the information technology, the energy storage systems and the automatic control system [1]. It is a real time system with a data transmission of demand and supply of electricity to enhance the modern energy management.

Renewable energy is an important part of smart grid technology. Each type of renewable energy is differentiated by the source of energy such as solar energy, wind, biomass, hydro etc. Solar energy (photovoltaic: PV) is used to reduce electricity bills for residential homes. There are many advantages such as system reliability, low operation cost and maintenance, clean energy and free energy resources. Many researches have studied about the appropriate PV installation for the residence [2] [3] [4]. They found that the simulation of PV sizing optimization that each residential house was very complicated which had to use many techniques such as economics, supply chain, and other depth factors etc. However, a good simulation of PV could save an electricity cost for the residence.

Thailand has two electricity tariff for the residential homes which are a normal tariff and TOU tariff. The TOU tariff shows an electricity cost per unit higher than the normal tariff in peak time (9.00 AM – 22.00 PM, Monday – Friday) [5]. But the electricity cost per unit of TOU tariff is lower than the normal tariff in off peak. The installation of PV can reduce an electricity consumption in peak time which the electricity cost in TOU tariff is lower than the normal tariff. Therefore, the PV installation and using to the TOU tariff can effectively reduce the electricity cost for residential houses. Syed et al. simulated the forecasting of PV sizing optimization with electricity management of TOU tariff [6]. They found that the house as the simulation can reduce the cost of electricity from the grid and reduce load demand for grid during peak time period.

Recently, Songpol et al. conducted a study on electricity cost saving simulation of changing to time of use rate (TOU) for residential homes at voltage level 220 - 380 volts [7]. The results showed that the savings depended on the electricity consumption per month and the ratio of electricity consumption in peak time periods. To illustrate, the customer who use the electricity consumption exceeding 420 units per month and the ratio of electricity consumption in peak time (α) less than 0.4. They can save electricity by changing to the TOU tariff. Furthermore, if the ratio of electricity consumption in peak time is higher than 0.55, it cannot save electricity by changing to the TOU tariff.

In order to reduce the electricity cost, the PV has been installed. Then, the percentage of electricity cost saving by changing to TOU tariff will be effective when the ratio of electricity consumption in peak time is minimal as shown in Fig.1. Therefore, this research study the PV size to achieve the benefit of TOU tariff. In the study, the solar radiation data of Phayao province has been numericalled and the electricity generation from PV has been used during peak time periods.

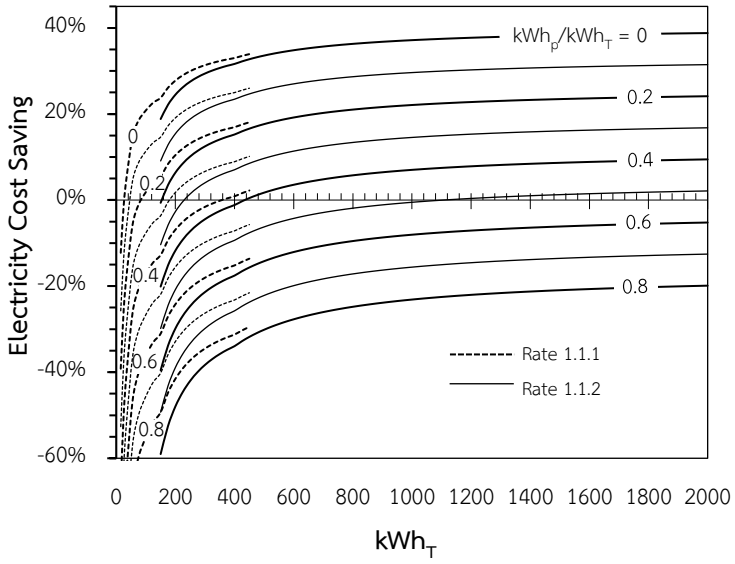


Fig. 1 Electricity saving cost of tariff no. 1.1.1 and 1.1.2 when using TOU tariff substitute to the normal tariff [7].

2. Research method

In this research, the residence using electricity more than 150 kWh per month (units per month) is considered. The evaluation of PV size that yields the benefit to the TOU tariff shows the procedure as Fig. 2.

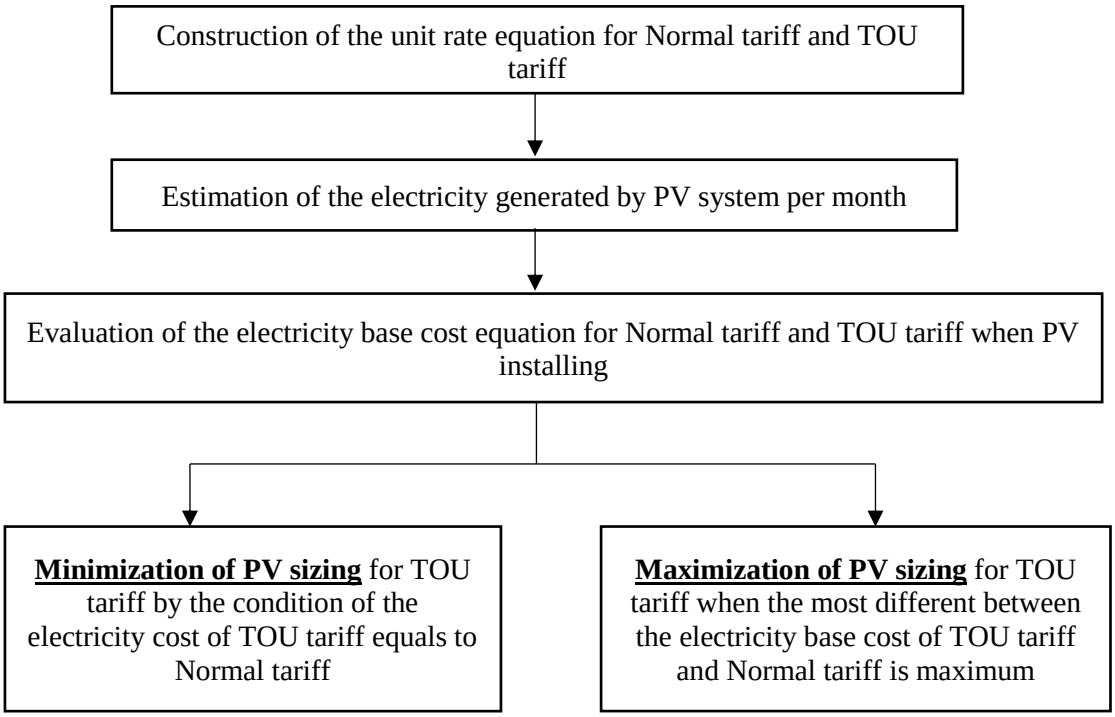


Fig. 2 The evaluating PV size procedure.

2.1 Unit rate for normal tariff and TOU tariff

The simulated electricity cost of a residence is an electricity customer refer to 1.1.2 rate and the

tariff announcement by the provincial electricity authority, 2015[5]. The simulation for the electricity base cost of normal tariff and TOU tariff will be numerically calculated the unit rate of the PV installation.

The unit rate of normal tariff and TOU tariff can be calculated using Equation (1) and (2) [7]:

$$UR_N = 3.2484 + 0.9734\left(1 - \frac{150}{kWh_T}\right) + 0.1999\left(1 - \frac{400}{kWh_T}\right) \quad (1)$$

Where:

$$1 - \frac{a}{kWh_T} = \begin{cases} 1 - kWh_T, & a < kWh_T \\ 0, & a \geq kWh_T \end{cases}$$

$$UR_{TOU} = 2.6369 + 3.163\alpha \quad (2)$$

Where: UR_N = The unit rate of normal tariff (Baht/kWh)

UR_{TOU} = The unit rate of TOU tariff (Baht/kWh)

2.2 The electricity generated by PV system

The electricity generated by the PV system per month can be calculated as the following equation [8]:

$$kWh_{PV} = I \times EF \times 30days \times PV \quad (3)$$

Where: kWh_{PV} = The electrical energy generated by the PV

I = Insolation (kWh/m²/day)

EF = An energy yield derating factor

PV = Size of photovoltaic (kW_P)

Greenzone (Thailand) recommended an energy yield derating factor is 0.7 [8] and department of alternative energy development and efficiency showing an Insolation for Phayao province is 4.67 kWh/m²/day [9].

Therefore:

$$kWh_{PV} = 98 \cdot PV \quad (4)$$

2.3 The electricity base cost when PV installing

When the PV system is installed, the total electricity consumption (kWh_T) will be reduced and the electricity bill will be also decreased. The electricity consumption equation after PV installation can be written as the following equation.

$$kWh_{T,NE} = \left(kWh_{T,E} - 98 \cdot PV\right) \quad (5)$$

The ratio of electricity consumption in the peak time will change as well. Considering that the electricity generated from the PV is used only during peak time (It may be necessary to install a battery

to store energy during the peak time). The ratio of electricity consumption in the peak time is as shown.

$$\alpha_{NE} = \frac{\alpha_E \cdot kWh_{T,E} - 98 \cdot PV}{kWh_{T,E} - 98 \cdot PV} \tag{6}$$

From equation (1) and (2) can be written to electricity base cost of each tariff as the following equations.

$$EC_N = kWh_{T.NE} \cdot UR_N \tag{7}$$

$$EC_{TOU} = kWh_{T.NE} \cdot UR_{TOU} \tag{8}$$

Where: EC_N = The electricity base cost of normal tariff (Baht)

EC_{TOU} = The electricity base cost of TOU tariff (Baht)

When replacing the equation (1) - (6) in equations (7) and (8), we obtain the electricity base cost equation for each tariff as the following equations:

$$EC_N = \left(kWh_{T,E} - 98 \cdot PV\right) \times \left[3.2484 + 0.9734\left(1 - \frac{150}{kWh_{T,E} - 98 \cdot PV}\right) + 0.1999\left(1 - \frac{400}{kWh_{T,E} - 98 \cdot PV}\right)\right] \tag{9}$$

$$EC_{TOU} = \left(kWh_{T,E} - 98 \cdot PV\right) \times \left[2.6369 + 3.1613\left(\frac{\alpha_E \cdot kWh_{T,E} - 98 \cdot PV}{kWh_{T,E} - 98 \cdot PV}\right)\right] \tag{10}$$

From equation (9) and (10), we will simulate the electricity consumption of residential houses with the use of electricity at 1,000 units and the ratio of electricity consumption in the peak time is 0.6. The chart can be compared to the electricity base cost of both tariffs as show in Fig.3.

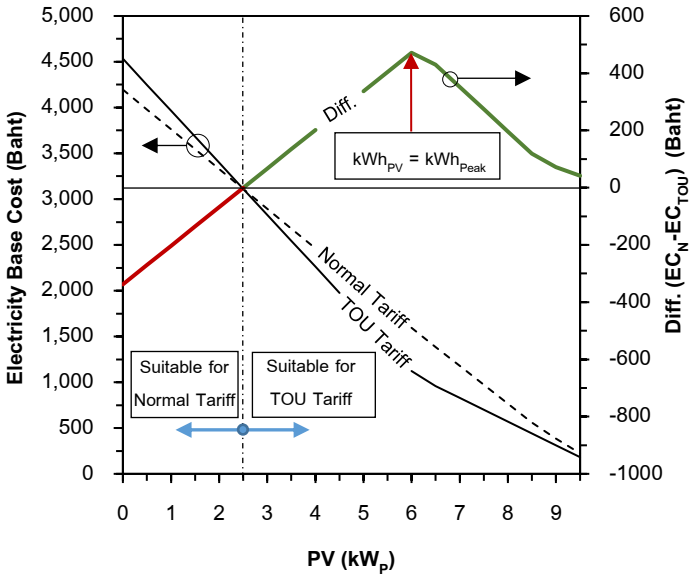


Fig. 3 Comparision of electricity cost of both tariffs at 1,000 kWh and α_E = 0.6 residence.

Fig. 3 shows that the installation of PV from 0 to 2.5 kW_P, the electricity of the normal tariff will be lower than the TOU tariff and the installation of PV from 2.5 kW_P, results in a TOU tariff lower than normal tariff. After installing PV over 6 kW_P, the differences of two tariffs will be gradually decreased. Due to the installation size of more than 6 kW_P, the ratio of electricity consumption in the Peak period is zero which the electricity cost per unit of TOU is a constant rate at 2.6369 baht per unit.

3. Results and discussions

3.1 The minimum PV sizing

Based on Fig. 3, when the electricity cost of TOU tariff equals to normal tariff, then this point shows the minimum PV size. This condition is defined by following equation:

$$EC_N = EC_{TOU} \tag{11}$$

Substitute equation (9) (10) into equation (11) will be

$$3.2484 + 0.9734\left(1 - \frac{150}{kWh_{T,E} - 98 \cdot PV}\right) + 0.1999\left(1 - \frac{400}{kWh_{T,E} - 98 \cdot PV}\right)$$

$$= 2.6369 + 3.1613\left(\frac{\alpha_E \cdot kWh_{T,E} - 98 \cdot PV}{kWh_{T,E} - 98 \cdot PV}\right) \tag{12}$$

Where:

$$1 - \frac{a}{kWh_{T,E}} = \begin{cases} 1 - kWh_{T,E}, & a < kWh_T \\ 0, & a \geq kWh_T \end{cases}$$

The equation (12) can be written as a PV sizing equation, which is based on the total electricity consumption before the PV installation ($kWh_{T,E}$) and the existing ratio of electricity consumption in peak time (α_E) as shown in Table 1.

Table 1 Equation for the minimum PV sizing.

Equation		Condition
$PV = (0.0127\alpha_E - 0.0024)\cdot kWh_{T,E}$	(13)	$if\ kWh_{T,E} - 98\cdot PV < 150$
$PV = (0.0205\alpha_E - 0.0103)\cdot kWh_{T,E} + 0.9709$	(14)	$if\ 150 < kWh_{T,E} - 98\cdot PV < 400$
$PV = (0.0234\alpha_E - 0.0132)\cdot kWh_{T,E} + 1.6748$	(15)	$if\ kWh_{T,E} - 98\cdot PV > 400$

Equation (13) - (15) can be used to create the minimum PV chart that will benefit from using TOU tariff as shown in Fig. 4.

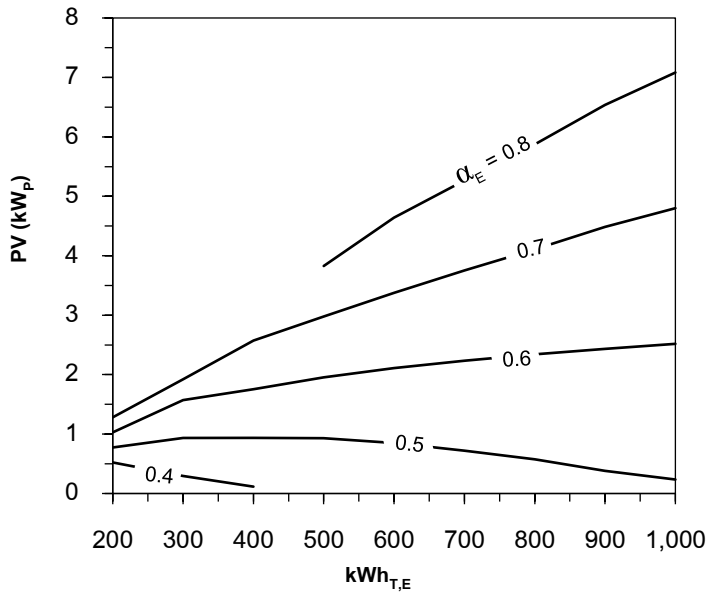


Fig. 4 Minimum of PV (kW_P) installation with TOU tariff for residence.

Fig. 4 shows the minimum PV size depended on the $kWh_{T,E}$ and the existing ratio of electricity consumption in α_E that will benefit from the TOU tariff. For example, the customer using the total electricity consumption before PV installation is 400 units per month and the existing ratio of electricity consumption in α_E is 0.7. Then, in order to benefit from the TOU tariff, a PV installation should be at 2.5 kW_P or more. Fig. 4 can be concluded that the customer who use the total electricity consumption before PV installation is 500 units per month and the existing ratio of electricity consumption in α_E at 0.8 cannot take advantage from the TOU tariff.

3.2 The maximum PV sizing

The evaluation of the maximum PV size will benefit from the TOU tariff. According to Fig. 3, the most different between the electricity base cost of TOU tariff and the normal tariff is the maximum PV size. In this point, the kWh_{PV} is equal to kWh_{Peak} and can be written the equation as

$$kWh_{PV} = kWh_{Peak} \tag{16}$$

Substitute equation (16) in equation (12) will be

$$PV = \frac{kWh_{TE} \times \alpha_E}{98} \tag{17}$$

The equation can be created as a chart to determine the maximum PV size that will result in the different electricity base cost between TOU tariff and normal tariff has been shown in Fig. 5.

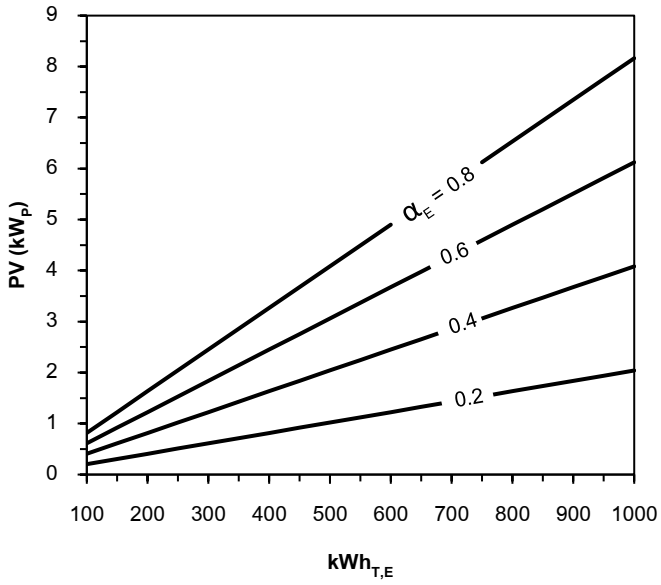
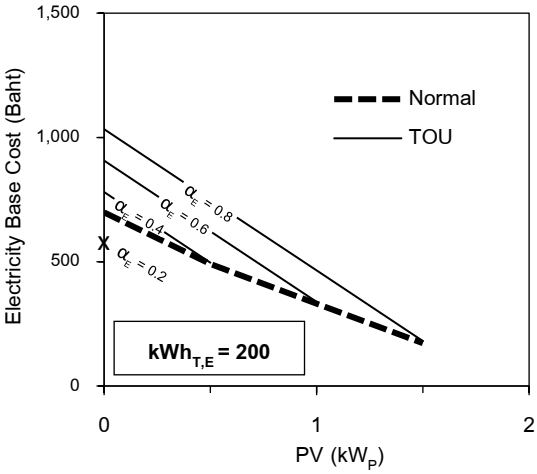


Fig. 5 Maximum PV installation.

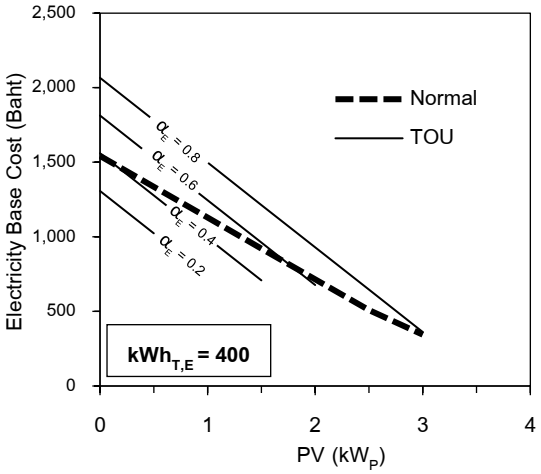
Fig. 5 shows that the maximum PV is depended on the total electricity consumption per month and the ratio of electricity consumption in peak time periods. For the example, the customer who uses electricity 500 units per month and the ratio of electricity consumption in the peak range at 0.4, the maximum PV installation is 2 kW_P. From the result, the maximum size of the PV installation is higher when the electricity consumption per month and the ratio of electricity consumption in peak time are increase.

3.3 Electricity chart for each residence

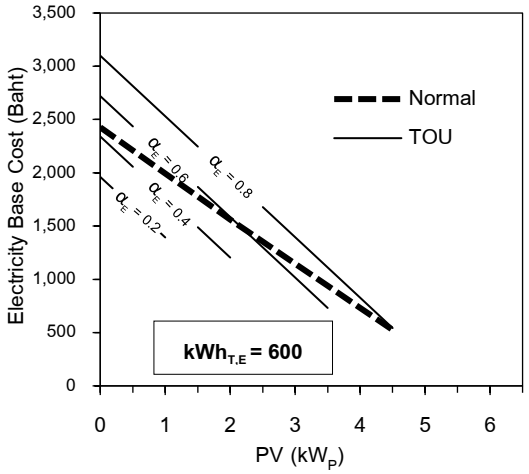
Fig. 3 shows the minimum size of PV that has benefited from TOU tariff. If the PV size is installed greater, the different electricity base cost between TOU tariff and normal tariff will also increase. The difference in data is useful for the customers to analyze economics. So, this part needs to show the comparison of both tariffs. According to equation (6) and (7), the charts are created for residence who use the electricity at 200, 400, 600, 800 and 1,000 kWh per month, as shown in Fig. 6.



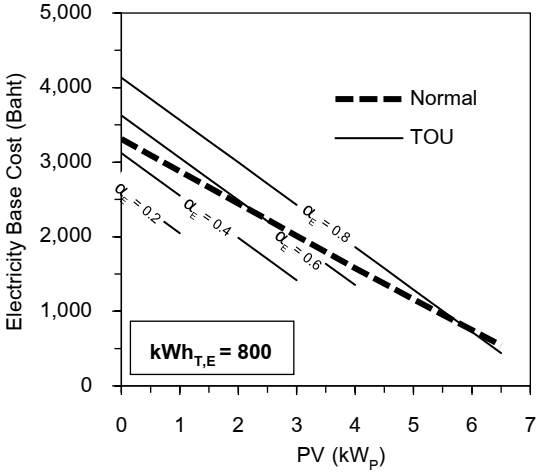
(a) $kWh_{T,E} = 200$



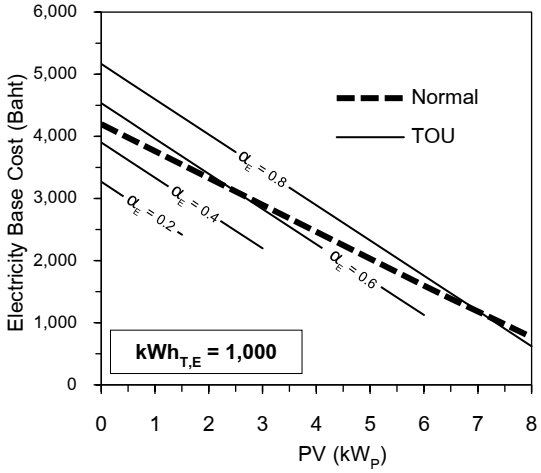
(b) $kWh_{T,E} = 400$



(c) $kWh_{T,E} = 600$



(d) $kWh_{T,E} = 800$



(e) $kWh_{T,E} = 1{,}000$

Fig. 6 Electricity base cost of normal and TOU.

Fig. 6 shows the electricity base cost of two tariff depending on the PV installed which are electricity consumption per month and the ratio of electricity consumption in peak time (α). There are 5 charts for customer analyzing the electricity base cost by themselves when installing various size of PVs. For the example, the customer who has electricity consumption at 400 kWh per month and the ratio of electricity consumption in α_E at 0.4. Then, if the residence installed PV at 1 kW_P with using TOU tariff, it will be charged about 900 baht per month. On the other hand, if the residence installed PV at 1 kW_P with use normal tariff, it will be charged at 1,100 baht per month as shown in Figure 6 (b).

3.4 Discussions

From the results, minimum and maximum PV that obtain the benefit from the TOU tariff are shown in selected chart as Fig. 4 and Fig. 5. The customers can use them to select the PV size for installation. In the past, there were no researcher presenting such information. However, this research consider that the electricity generated from the PV is used only during peak time periods. The battery for supporting the electricity in peak time have not studied yet.

4. Conclusions

The simulation of minimum and maximum PV size that benefit from TOU tariff for residence with electricity consumption exceeding 150 units per month and at voltage level lower than 22 kV, the conditions are the PV installed in Phayao province and the generated electricity from PV using only during peak time periods. The results can be concluded;

1) Minimum and maximum PV sizing chart can be obtained. The customer can choose the appropriate PV from these charts.
2) The minimum PV size depends on the total electricity consumption before PV installation ($kWh_{T,E}$) and the existing ratio of electricity consumption in α_E. The customer who uses the total electricity consumption less than 500 units per month and the ratio of electricity consumption in α_E more than 0.8 will not benefit from the TOU tariff.
3) The maximum PV size depends on the total electricity consumption per month and the ratio of electricity consumption in peak time periods. If the electricity consumption per month and the ratio of electricity consumption in peak time were increasingly high, the maximum size of the PV installation should be accordingly enlarged as well.

5. Reference

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