Potential Electricity Bills Savings Based on Customer Load Profile with Solar PV: A Case Study

H Atikah[1,a)] and C S Tan[2,b)]

[1]*College of Graduate Studies, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.*
[2]*Institute of Energy Policy and Research, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.*

[a)]Corresponding author: hajaratikah@gmail.com
[b)]chingsin@uniten.edu.my

Abstract: With the high demand in electricity consumption nowadays, it is crucial for regulator and utilities to ensure sufficient energy supply to meet electricity demand. Electricity demand is influenced by several factors such as number of customers, customer behavior, working hours, weather condition and holidays. Integrating renewable energy technology as part of electricity generation for self consumption has indirectly provide an option to customer to reduce his electricity consumption from the grid and help to save his electricity bill. One of the simplest solutions to install renewable energy sources is by installing rooftop solar photovoltaic (PV). In this paper, the economic feasibility of installing solar PV is discussed based on commercial customer load profile. This paper also presents the suitable PV sizing and the payback analysis based on customer's load profile. A commercial customer's load profile in Petaling Jaya, Selangor is used as a case study for this analysis. This study indicates that the potential electricity bill saving with the integration of solar PV system on customer's building rooftop can be achieved up to 28% if 1,256kW solar PV system is installed. The payback period with this solar PV installation is approximately around 9 years.

INTRODUCTION

In a deregulated electricity supply industry, reducing system peak demand will help to disproportionate system generation costs. In other words, the system generation costs is high during peak demand and vice versa. Therefore the reduction of the system peak demand will help to drive a lower generation costs and bring benefit in term of a lower customer's electricity tariff. However, this situation is hardly enjoy by any customers due to the nature of their daily activities or busineses but acheivable through energy efficiency measures. Customer's behaviour change on electricity consumption is seen to be the simplest yet the hardest way to improve electricity consumption which require perseverance. This can be achieved in a more sustainable energy in the future through customer's feedback on their energy consumption based on smart metering system as highlighted in [1]. The introduction of the real-time demand response is evidance to help reducing customer's electricity bills with a better way of managing electricity consumption [2]. Two algorithms named controllable device first (CDF) and shiftable class first (SCF) were developed by [2] to reduce the consumption of electricity mainly in the industry. The former algorithm has shown 25.1% in annual savings while the latter shown 25.3% in annual savings.

The time-of-use pricing is another demand response mechanism that accurately reflect electricity bill of a customer. Time-of-use pricing offers the customer a lower electricity rate during off-peak hours and higher electricity rate during peak hours. This directly helps customer managing their electricity consumption in a more efficient way. Other studies also indicate that coupling a battery energy storage system with solar PV helps to reduce electricity bills [3-7]. Study in [3] indicates that real time battery energy storage control based on its state of charge can bring savings in residential via a proposed conditions of the customer load profile and electricity rate. Researchers in [5], proposed a mixed integer Nonlinear programing using python optimization modeling language to minimize the electricity cost for time-of-use and net-metering customers with energy storage. Similarly, in [6] the economic feasibility of residential behind the meter battery energy storage was discussed. The study indicates that even though battery energy storage system enables end-users to purchase energy and store it in the battery when the electricity price is low and consume the energy later when the electricity price is high, batteries are subject to economic and functional limitations because they are degradable systems and the performance declines over time. However, a research by [7], concluded that installing a battery energy storage system may not be economically beneficial to residential in Southeast Queensland with solar PV. This is mainly due to the battery energy storage cost that exceeded the electricity savings. Most of the studies focused on peak demand shaving strategies using energy storage to maximise the cost savings [5-7].

In [8], an intelligent charging system algorithm called SmartCharge was developed and deployed for residential to lower their electricity bill. This study shows that the system deployed at 22% of 435 homes reduces the aggregate demand peak by 20%. For a typical home's the electric bill can be reduced by 10%-15% using realistic battery capacities as reported. Following the technology enhancement, various solutions were introduced to promote savings in the customer's electricity bills. Researcher in [9] has conducted study on the economic benefits and the payback periods of rooftop solar panels in Australia. The paper has highlighted several factors affecting economic benefits of rooftop solar panel including rating of the rooftop solar panel, the pattern of electricity consumption by the household, the location of the household, electricity consumption charge and feed-in tariffs (FiT) offered by the utility. Based on the analysis carried out, the study concluded that for a typical Australian household which consumes 5,500kWh annually and 50% of the solar PV generation is for own consumption while the remaining to be exported to the utility under FiT scheme, the payback period was between 5 and 11 years.

Maximizing electricity bill saving with integration of PV can be achieved through understanding and utilisation of customer's load profile. Load profile has been used by many researchers as an efficient, organized and systematic tool for energy tariff scheme design, planning and load management in many countries [10]. Due to the diversity of customers, statistical methodology has been used for preparation of aggregated load profile. Reference in [11] compares, correlates data and analyses the results to determine the different factors that influence the load profiles which significantly varied between different occupancy types, housing data and customer behaviour. There is also an alternative method to do load modelling as specified in [12] by modeling the load composition rather than actual monitoring. The main obstacle in this load modelling will be on the validation of data. Reliance on the out-of-date data is not recommended because such data sets do not necessarily accurately represent end-use load profiling. It presents a method which involves updating outdated load studies with current mean annual unit energy consumption data.

Paper in [13], describes that customer's load profile is poor if obtain from the classic meter or electro-mechanical meter as compared to smart meter. Smart metering systems could allow electric distribution companies to monitor the electrical power conditions practically in every point of network. The load profiling methodology uses self-organization techniques to process data, identify existing load classes or patterns, classify customers according to classes and generate typical load profiles. For the determination of customer's classes, every customer must be characterized by the following primary information: daily (monthly) energy consumption, minimum and maximum loads. Therefore with a detail load profile information, it will enable end-customers to obtain greater savings in their electricity bill by reducing his/her energy consumption with the usage of energy efficient products and energy harvesting from solar PV.

In order to quantify the electricity bill saving, it is important to know what is the customer's electricity tariff so that monthly potential electricity bill saving can be determined before and after installing of solar PV based on the pre-determined solar PV sizing. However, saving in electricity bill depends on a number of factors such as direct hours of daily sunlight, solar PV sizing and angle of the rooftop. Nevertheless electricity rates play the biggest role in determining how much solar PV installation can help in maximizing electrictity bill saving. The volatile nature of electricity prices is an added incentive for solar PV whereby the energy costs is locked at a constant rate with solar PV without needing to consider the variable utility rates.

This paper highlights the potential electricity bill saving based on a financial instituition customer's load profile located in Petaling Jaya, Selangor. In this paper, customer's load profile pattern is discussed and an analysis is carried out to determine potential electricity bill saving with different solar PV sizing based on customer's load profile and finally its payback period is determined.

METHODOLOGY

A financial institution commercial customer load profile in Petaling Jaya, Selangor was obtained and shared by Suruhanjaya Tenaga. The load profile collected is between 1st and 31st May 2018. The load profile measured at the customer's output meter has a 10-minutes interval reading. The half-hourly interval data was created based on the load profile readings. The characteristic of the customer electricity consumption of the half-hourly load profile pattern were observed and analysed. Two weekly load profiles were generated to observe the difference in operation between weeks. The average minimum and maximum electricity consumption from the customer load profile will be used to determine the solar PV sizing. In this paper, the solar PV sizing was based on the average maximum demand. The 70% of the average maximum demand is set as the lowest solar PV capacity and increases gradually up to 100% solar PV capacity which is equivalent to the average maximum demand. The potential electricity bill saving was calculated according to different solar PV sizing. The payback period was then identified with different solar PV sizing based on the commercial customer's load profile used. The solar PV module chosen for this analysis is tabulated in Table 1.

TABLE 1. Solar PV Module Parameters

Parameter	Description
Brand	JA Solar
Rated Maximum Power	370W
Maximum Efficiency	18.6%
Dimensions	1993mm x 998mm x 30mm

Note: 97% nominal power for first year

The electricity tariff for this commercial customer is Tariff B – Low Voltage Commercial Tariff and the structure is as in Table 2.

TABLE 2. Electricity Tariff Structure

Tariff	Unit	Rates
For the first 200kWh (1 – 200kWh) per month	sen/kWh	43.50
For the next kWh (201kWh onwards) per month	sen/kWh	50.90
The Minimum Monthly Charge	RM	7.20

The output generated from the solar PV is calculated as follow,

$$E = A \times R \times H \times PR \tag{1}$$

Where E is the solar output generated in W, A is the total area of solar PV in square meter in m^2, R is the efficiency of the solar PV, H is the solar irradiance on the panel, W/m^2 and PR is the performance ratio. PR used in this paper is 0.97.

To obtain the payback period, this paper has made a reference to a report produced by International Renewable Energy Agency (IRENA) on the average total cost of solar PV systems installation [14]. In this study, it is assumed that the average total cost of solar PV systems installation is 1,600 USD/kW in 2018. The simple payback period is calculated as follow,

$$\text{Payback Period, year} = \frac{\text{Total Cost of Solar PV Installed}}{\text{Annual Savings}} \tag{2}$$

RESULTS AND DISCUSSIONS

Figure 1 shows the daily commercial customer's load profile usage between Monday and Sunday between 1^{st} and 7^{th} May 2018. It indicates that the commercial customer started it's operation as early as 6.00 a.m and end at 6.00 p.m. It can be observed that the electricity consumption gradually decreasing to a minimum by 10.30 p.m. The minimum electricity consumption for this commercial customer ranging between 300kW and 530kW and it occurs during weekend. On average, the consumption is about 400kW on Saturday and Sunday. The load pattern also summarizes that the daily maximum demand varies between 1000kW and 2000kW during operations i.e, office hours. The weekdays load consumptions show a flat consumption for a duration of 12 hours during weekdays. Based on the load pattern, it shows that the commercial building does not operating during weekend and holiday seasons.

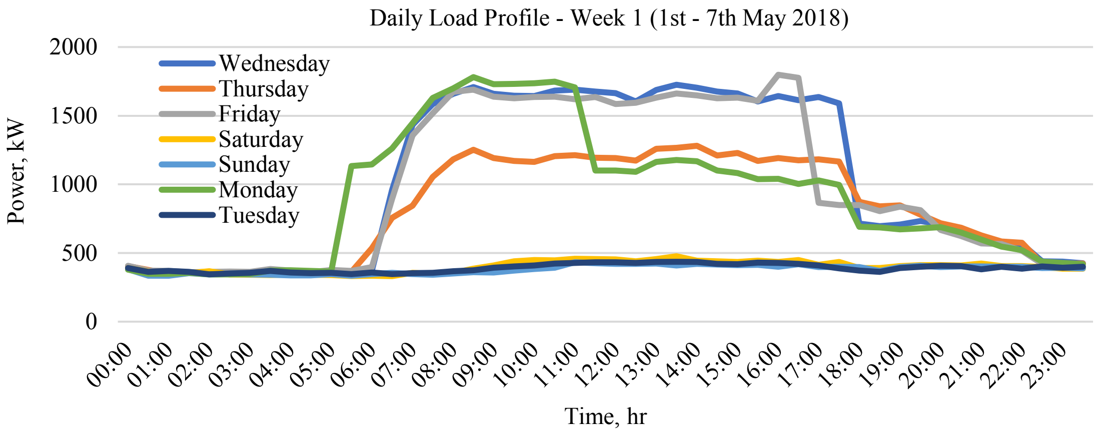

FIGURE 1. Customer's load profile week 1

Figure 2 illustrates a similar load pattern profile as shown in Fig. 1 for week 2 between 8th and 14th May 2018. It also indicates that there's no significant difference in operation's time during weekdays and weekend between week 1 and week 2. On normal operation days, Wednesday and Monday/Thursday shows the highest and the lowest electricity consumption respectively each week. Based on the load consumption recorded, the average maximum dan minimum demand of the commercial customer are 1795kW and 340kW respectively. Hence, solar PV sizing should be designed based on the customer's load pattern and maximum demand. Therefore, multiple solar PV sizing are simulated to achieve the potential savings. The solar PV sizing are calculated based on the customer's daily average maximum demand as depicted in Table 3.

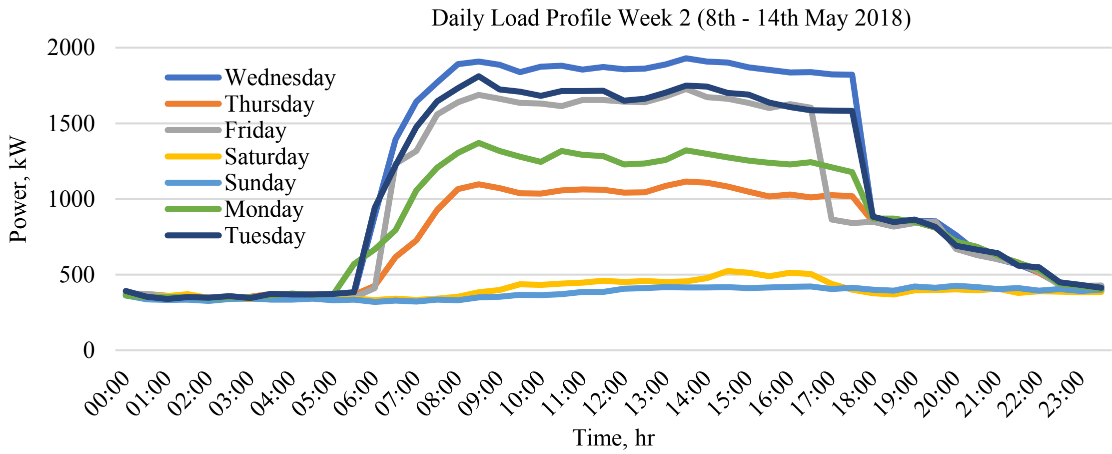

FIGURE 2. Customer's load profile week 2

TABLE 3. Solar Photovoltaic (PV) sizing based on average maximum demand

Percentage (%) of average Maximum Demand	Solar PV Capacity (kW)
60	1,077
70	1,256
80	1,436
90	1,616
100	1,795

The monthly average solar irradiation on the horizontal surface in Petaling Jaya were obtained from [15]. The maximum and values of solar irradiation is 16.99 MJ/m2/day and the minimum value recorded is 14.54 MJ/m2/day. The annual average solar irradiation in Petaling Jaya is reported around 15.82 MJ/m2/day. Therefore, the maximum value of solar irradiation is used to calculate the maximum output generated from the solar PV as shown if Figure 3.

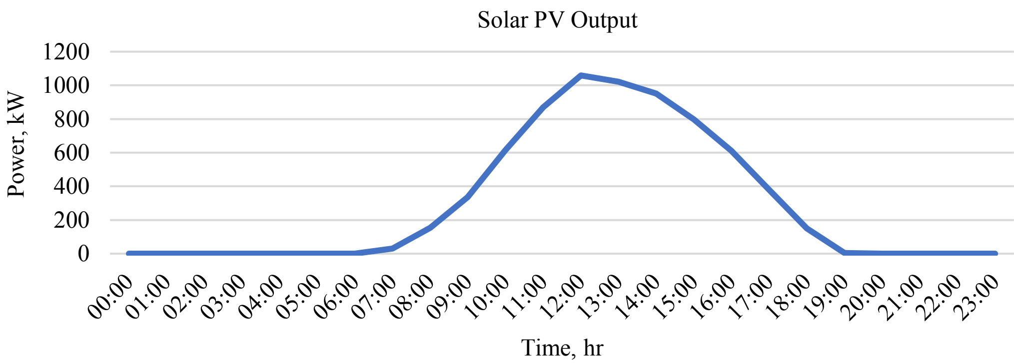

FIGURE 3. Solar PV Output Generated

Figure 4 illustrates the customer's load profile during normal operation and total solar PV output generated with a varying percentage (%) of average maximum demand between 70% and 100% . The solar PV output is calculated using Equation (1) based on the maximum irradiation value in Petaling Jaya. The energy generated from solar PV installation is determined and hence translated into savings in customer's electricity bill.

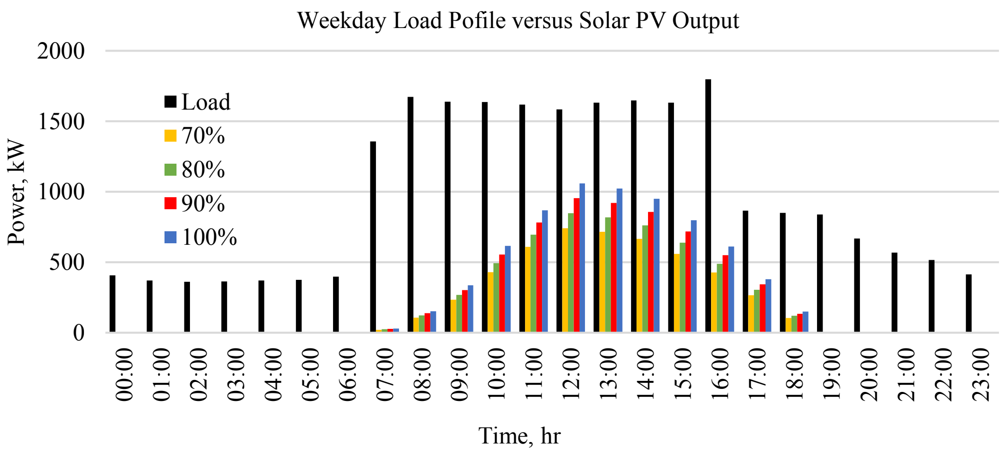

FIGURE 4. Weekday Load Profile vs Solar PV Output

Figure 5 shows the customer's load profile during weekend whereby the load demand recorded is low. Eventually, there is an excess of energy generated from solar PV system during midday. Hence, the load consumption between 10.00 a.m and 4.00 p.m can fully utilized the energy generated from any proposed solar PV system.

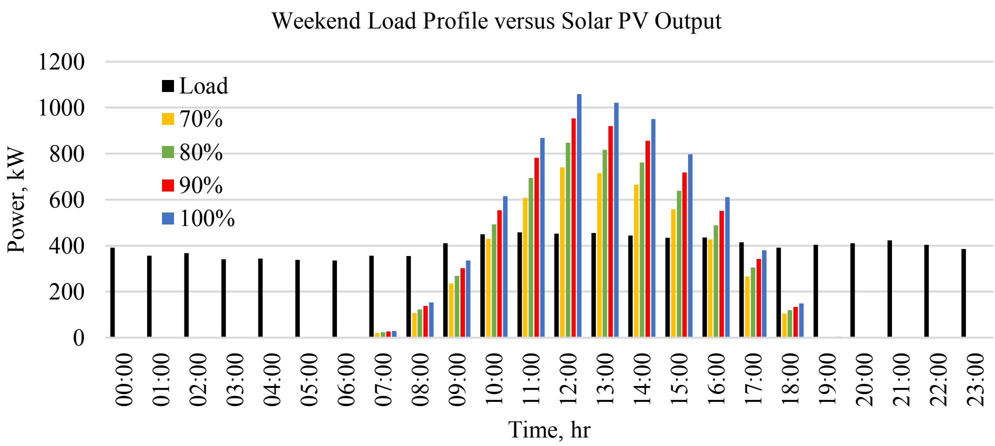

FIGURE 5. Weekend Load Profile vs Solar PV Output

Figure 6 shows the annual savings calculated with different solar PV sizing in percentage of Maximum Demand of the customer under the study. The results obtained from the analysis shows that solar PV generated with different sizing (capacity) can help customer to save up to 28% in monthly bill if a total capacity of 1256kW solar PV is installed. It is known that larger PV capacity will result in greater electricity bill savings. However, the solar PV capacity to be installed is constraint off by the existing rooftop size. The payback period of this study is around 9 years for this case study based on the customer's maximum demand.

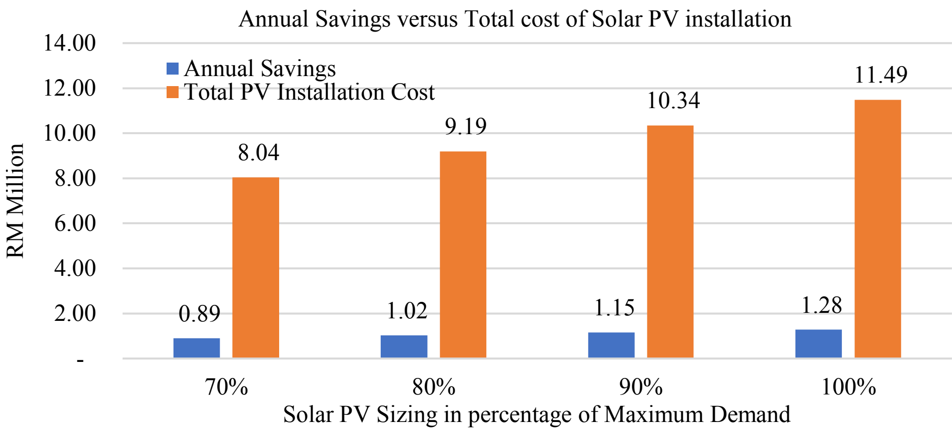

FIGURE 6. Total Annual Savings and Installed Costs

CONCLUSIONS

This study indicates that customer will be able to reduce their electricity bill consumption with the integration of solar PV system on the rooftop of their building. Customer is able to save their montly electricity up to 28% if a total solar PV capacity of 1256kW is installed. The payback from this study indicate the payback period is approximately around 9 years. The integration with battery storage is not consider in this paper. Inclusion of battery energy storage may help to save in electricity bill by selling back the excess energy to utility. More details study on the dynamicity of the load profile coupled with solar PV and battery energy storage will provide a better understanding of the electricity bill savings in long run.

ACKNOWLEDGEMENTS

The authors are grateful and appreciative to Suruhanjaya Tenaga for sharing data on customer load profile for the study. This research work is supported and funded by Universiti Tenaga Nasional (Innovation and Research Management Centre, iRMC) internal grant - 10436494/B/2019061. Any opinions, findings and conclusions expressed in this paper are from the authors and do not necessarily reflect the views of the Suruhanjaya Tenaga, Universiti Tenaga Nasional or the Institute.

REFERENCES

1. Zhifeng. Qiu, Geert. Deconinck, "Smart Meter's Feedback and the Potential for Energy Savings in Household Sector: A Survey", IEEE International Conference on Networking, Sensing and Control Delft, pp. 281-286 (2011).
2. N.Y.Olawuyi, M.F.Akorede, E.Femi, A.A.Ayeni, R.G.Jimoh, "Real-time Demand Response Algorith for Minimising Industrial Consumers Electricity Billing", IEEE 3rd International Conference on Electro-Technology for National Development (NIGERCON), pp. 1061-1066 (2017).
3. Huangjie Gong, Oluwaseun Akeyo, Vandana Rallabandi, Dan M.Ionel, "Real-time Operation of Smart Homes with PV and Battery Systems under Variable Electricity Rate Schedules and Transactive Power Flow", IEEE 7th International Conference on Renewable Energy Research and Applications (ICRERA), pp. 1392-1395 (2018).
4. Travis Simpkins, Kate Anderson, Dylan Cutler, Dan Olis, "Optimal Sizing of a Solar-Plus-Storage System for Utility Bill Savings and Resiliency Benefits", IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), pp. 1-6 (2016).
5. Tu A.Nguyen, Raymond H.Byrne, "Maximizing the Cost-savings for Time-of-use and Net-metering Customers Using Behind-the-meter Energy Storage Systems", North American Power Symposium (NAPS), pp. 1-6 (2016).
6. Ahmed Zurfi, Ghaidaa Albayati, Jing Zhang, "Economic Feasibility of Residential Behind-the-meter Battery Energy Storage Under Energy Time-of-use and Demand Charge Rates", IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), pp. 842-849 (2017).

7. Dan Hui Tang, Dr.Daniel Eghbal,”Cost Optimization of Battery Energy Storage System Size and ycling with Residential Solar Photovoltaic”, Australasian Universities Power Engineering Conference (AUPEC), pp. 1-6 (2017).
8. Aditya Mishra, David Irwin, Prashant Shenoy, Jim Kurose, Ting Zhu, “SmartCharge: Cutting the Electricity Bill in Smart Homes with Energy Storage” Third International Conference on Future Systems: Where Energy, Computing and Communication Meet (e-Energy), pp. 1-10 (2012).
9. Muhammad Hayat, Farhad Shahnia, Ali Arefi, Herbet Iu, Tyrone Fernando, “Comparison of the Economic Benefits and the Payback Periods of Rooftop Solar Panels in Australia”, 3rd International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET), pp. 113-117 (2017).
10. Union of the Electricity Industry, “Metering Load, Metering Load Profiles and Settlement in Deregulated Markets”, eurelectric, pp. 1-67 (2000).
11. Abidur Rahman, Syed Ishraq Chowdhury Arnob, “Developing Load Profile for Domestic Customers of Dhaka City through Statistical Prediction”, 3rd International Conference on Electrical Engineering and Information Communication Technology (ICEEICT), pp.1-6 (2016).
12. C.M. Colson, M.H. Nehrir, “An Alternative Method to Load Modelling for Obtaining End-Use Load Profiles”, 41st North American Power Symposium, pp. 1-5 (2009)
13. D. Gerbec, S. Gasperic, I. Smon, F. Gubina, “An Approach to Customers Daily Load Profile Determination”, IEEE Power Engineering Society Summer Meeting, Vol. 1, pp. 587-591 (2002).
14. IRENA, “Renewable Power Generation Costs in 2014”, (2015).
15. Abdul Majeed Muzathik, Wan Mohd Norsani bin Wan Nik, Khalid bin Samo, Mohd Zamri Ibrahim,”Reference Solar Radiation Year and Some Climatology Aspects of East Coast of West Malaysia”, American Journal of Engineering and Applied sciences, Vol. 3, No. 2, pp. 293-299 (2010).