VOL. 13, NO. 19, OCTOBER 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

BATTERY ENERGY STORAGE SYSTEM SIZING FOR HIGH PENETRATION OF SOLAR PHOTOVOLTAIC SYSTEMS IN LOW VOLTAGE DISTRIBUTION NETWORK

Meysam Shamshiri, Chin Kim Gan and Nur Izzati Zolkifri and Kyairul Azmi Baharin
Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Malaysia
E-Mail: meysam@utem.edu.my

ABSTRACT

The integration of high penetration photovoltaic (PV) system at low voltage (LV) distribution network has begun to introduce many challenges for electricity utility companies from the technical and economic aspects. In Malaysia, the NET-metering scheme is implemented with the aim to encourage the*in situ* solar energy consumption before exporting any excess to the grid. Nevertheless, during the high PV generation and low load consumption period, the excess power can be stored in a Battery Energy Storage System (BESS) to enable higher operation flexibility for network operators. Thus, the BESS needs to be sized properly based on the consumers' type of premises and capacity of PV generation system. This is to ensure optimum BESS operational efficiency. Hence, this paper investigates BESS sizing for a typical Malaysian double-story house with 4kW rooftop PV system. The load profile is captured from the group of normal house and PV generation profiles are taken from real data captured at Universiti Teknikal Malaysia Melaka. The results show that different sizes of BESS have significant impacts on the net load profile of the houses after connecting the battery. The optimum sizing of the battery reduces the maximum demand and smoothen the net load profile by storing the excess generation and dispatch it at the time of high demand. The Load Factor (LF) and Variability Index (VI) are the two-main metrics that have been considered in the study. The results show significant improvement of these metrics after the optimum BESS integration.

Keywords: solar PV, battery energy storage system, distribution network.

INTRODUCTION

The proliferations of energy demand and rapid depletion in energy sources have encouraged researchers in conducting more in-depth research regarding renewable energy to meet the energy demand. Photovoltaic (PV) solar system is one of popular renewable energy sources particularly in countries with tropical climate located in the equatorial area[1-3]such as Malaysia. The production of solar energy is influenced by weather, passing-clouds and the movement of sun in a day which could affect the solar PV's output power[3]. Obviously, high penetration rate of PV generation systems contribute several advantages such as reducing the greenhouse emission, reducing the use of fossil fuel in electricity and increasing the amount of energy independence [5]. Unfortunately in grid generation, high PV penetration would lead to reverse power flow to the grid and high network losses due to high generation power supplied during low demand period[6], [7]. This often occurs in residential areas installed with PV systems. During the midday, it generates power that is not consumed because the residents are usually not at home. Thus, combination of PV system and battery energy storage in a residential area would be a great combination in tackling issues of reverse power flow and enable greater flexibility.

Battery Energy Storage System (BESS) is a technology that used for storing energy and convert it to electricity for supplying end-users' power demand[1], [2]. Once generated power is more than required demand, the excess energy can be stored and used during peak demand. Since the conventional power grid is designed based on the idea of balancing between generation and demand, the integration of large size of storage system needs to be studied. The impacts of battery storage has been studied by many researchers in recent years[10][12]. More specifically, during high penetration level of PV, the battery storage can play significant roles to mitigate the negative impacts. This paper studies the rooftop grid-connected PV system at LV distribution level in for normal house/premises in Malaysia. By applying the NET Metering scheme in Malaysia, the house owners are encouraged to generate energy for self-consumption first. The storage system such as battery is one of the promising technologies that can be installed beside the PV system to enhance its efficiency by charging and discharging the battery in a timely manner. The size and rating of the battery must match the installed PV power output to bring maximum benefit for users while increasing the battery's lifecycle and minimizing the maintenance. One research argues that a big battery size is not encouraged if the battery is only supposed to cover short solar energy production gaps since the grid is accessible as back-up [13]. However, there is a need to consider the BESS sizing based on full day usage (24 hours). Hence, this paper performs an analytical approach to find the adequate size and rating of the battery for houses with rooftop grid-connected PV system.

METHODOLOGY

The main aim of this paper is to allocate the battery at the LV end-user level to increase the maximum benefits of installed grid-connected PV system with NET-Metering scheme in Malaysia. Hence, the Malaysian residential load profile with real captured solar irradiation

have been used in this paper. This paper performs the After Diversity Maximum Demand (ADMD) suggested by TNB load model for simulating the residential households' load. The ADMD for different types of house and consumptions in Malaysia is shown in Table-1. In this paper, a double story house in rural area has been utilized. In addition, all consumers are modelled as constant power factor equal to 0.95. Moreover, a typical aggregated Malaysian domestic load shape as shown in Figure-1 was used in this study [14]. Figure-2 shows the PV profile for 'variability day' that is captured at the Faculty of Electrical Engineering at UTeM. The comprehensive study on types of PV captured profile has been studied in[1]. As can be seen fromFigure-1 andFigure-2, the incidence of PV generation and maximum load demand are not covered by each other. Therefore, during the peak generation of PV the level of exporting power to the grid is very high which does not march the principle of the NET-Metering scheme to achieve maximum benefit. Therefore, this paper proposes to install battery storage to charge the battery during peak generation and discharge the battery during peak demand. The impacts of parametric sizing of BESS on load profile for a normal household with typical residential load profile is studied and the impact of PV during the maximum PV generation period against the minimum demand period with BESS integration is investigated.

Table-1. Residential maximum demand for domestic consumer sub-classes or premises in urban area [15].

No.	Type of premises	Rural (kW)	Suburban (kW)	Urban (kW)
1	Low-cost flats, single storey terrace, studio apartment (<600 sq ft)	1.5	2	3
2	Double storey terrace or apartment	3	4	5
3	Single storey, semi-detached	3	5	7
4	Double storey, semi-detached	5	7	10
5	Single storey bungalow & three-room condominium	5	7	10
6	Double storey bungalow & luxury condominium	8	12	15

Two indices that can show the impacts of BESS on load profile is Variability Index (VI) and Load Factor (LF). The ratio of VI and LF before and after installation of BESS can show the effectiveness of battery size and level of success in designing the suitable BESS for different types of houses. The VI indicates the rate of changes in power consumption during a day based on resolution time load profile and its equation can be written as follows:

$$VI = \overline{\left(\left| \frac{P(t) - P(t-1)}{\overline{P}} \right| \right)} \quad (1)$$

where, VI is variability index of load profile, P represents the power at time t and $\overline{P}$ is the average power.

The LF indicates the total load divided by the peak load in a specified period that can be written as follows:

$$LF = \frac{\sum P}{Max(P) * (Number\ of\ Study\ days * Time\ resolution)} \quad (2)$$

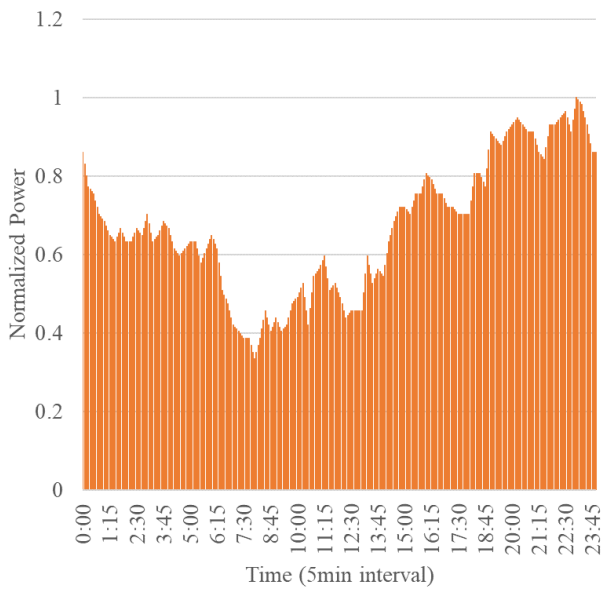

Figure-1. Malaysian residential load profile.

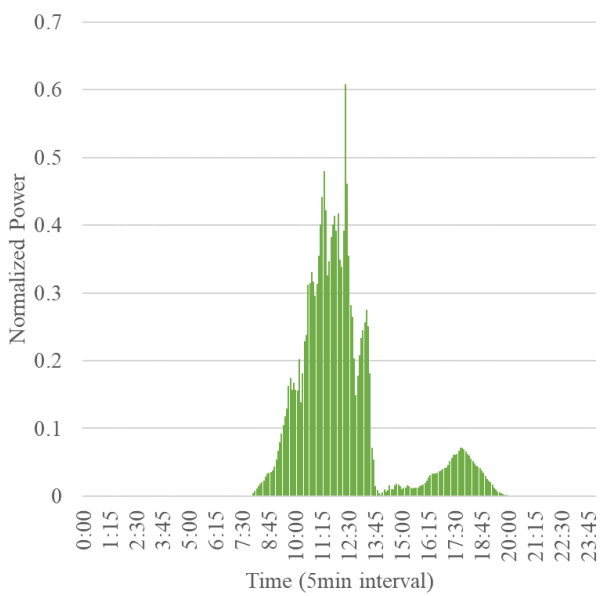

Figure-2. Typical PV generation for variability day in Malaysia.

Modelling BESS

This paper utilizes the OpenDSS software as the simulation tool and power flow engine. All the power system equipment can be modelled in this software for time series power flow calculation. The BESS can be modelled in OpenDSS with different methods of operation such as "Follow" and "load shape". In this paper, the "load shape" method is used to charge and discharge the battery based on the generated battery profile. The battery charges during the less power demand and discharging during high demand. In other words, battery can be charged once the PV generation is more that power demand and can be discharged during night hours with no PV generation. In general, the load profile can be generated using net profile obtained from the load shape and PV profile that can be written as follows:

$$Battery\ shape = Power\ (without\ battery) - average\ power$$

Figure-3 shows the generated battery shape that is obtained from load shape after 100% PV penetration. As can be seen from the figure, the average value of the load shape is considered as the point of charging/discharging changes status. In other words, the battery starts to charge once the power consumption is less than the mean value of the load shape and starts to discharge once the demand exceeds the mean value.

One of the main concerns of designing the battery for a house with an integrated PV system is the suitable sizing of the battery to increase the life cycle of the battery with optimum operation. The State of Charge (SoC) of the battery is the factor that needs to be monitored during the day to make sure that the battery status is under control. OpenDSS software gives this parameter in time series power flow to monitor SoC in real time. In this study, four different case studies have been considered, which are under-sizing, oversizing, non-optimum and optimum BESS sizing for a double-story houses with rooftop PV system, respectively. Hence, next section shows all results of BESS integration in order to investigate the proper size of the battery.

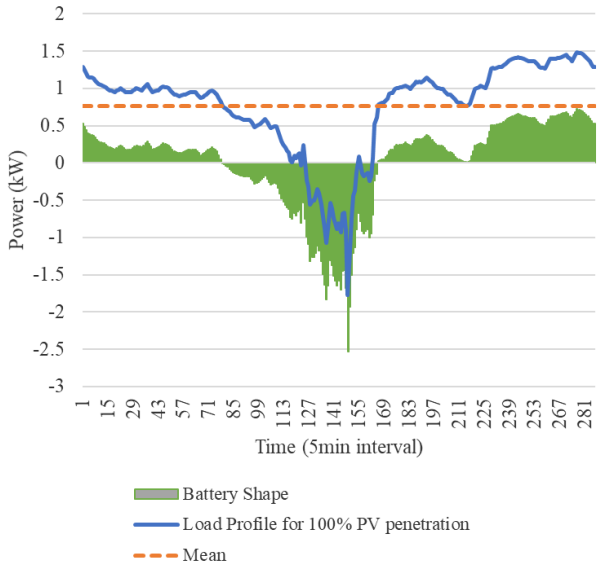

Figure-3. The battery shape during 100%PV penetration.

RESULTS AND DISCUSSIONS

As discussed above, the parametric evaluation of battery sizing has been investigated in this paper. The installed PV size at rooftop double story house for this case study is considered 4kW with real captured variability irradiance profile. The results of this section aim to highlight the impacts of different sizes of the battery with same battery charging/discharging profile might be resulted in different impacts on net load profile. As can be seen from Figure-4, the load profiles of two continuous days with different sizes of BESS ranging from 1kW to 11kW has significant impacts on the net load profile. In this case study, the BESS starts to discharge the battery once the power demand is greater than 0.8kW and charge the battery once it is lower than 0.6kW. If the battery size is very small with respect to the amount of required power demand, it will get discharged very fast and cannot operate for the whole day. As can be seen from Figure-5, once the battery is fully discharged, it needs to wait for the next charging time domain. As same as the fast discharging, the battery can be charged quickly during the charging status, and once it gets fully charged, it cannot help to consume the reverse power flow.

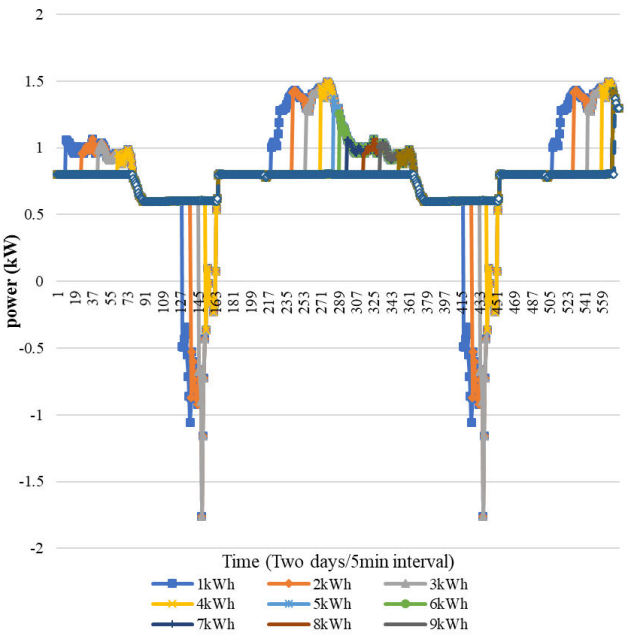

Figure-4. Battery sizing from 1kWh to 11kWh with 0.6kWh charging threshold and 0.8kWh discharging threshold.

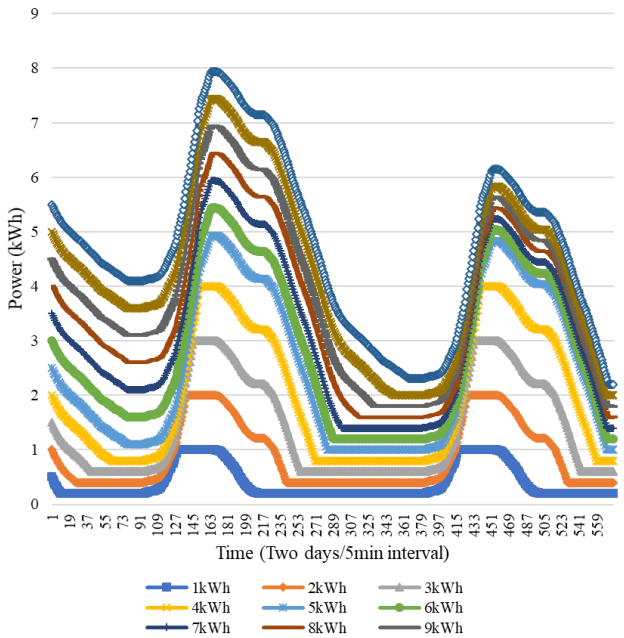

Figure-5. Battery sizing from 1kWh to 11kWh with 0.6kWh charging threshold and 0.8kWh discharging threshold.

Thus, the sizing of the battery should be designed based on the amount of energy that needs to be delivered to the customer to stabilize the load profile. In other words, if the battery size is suitable for the house it can help to smoothen the load profile of the house by charging and discharging it at the adequate time. As a result, the benefits of BESS at the load side can be summarized as reducing the maximum peak demand, filling the load profile valley during low power consumption and high PV generation as well as avoiding reverse power flow. To investigate the detailed impacts of different battery sizes on consumer load profile, the following subsections have been introduced to emphasize the under-sizing, over-sizing and optimum-sizing of BESS impacts in different cases.

Case No. 1, under-sizing battery

This case aims to show how the under-sizing BESS can influence the net load profile. In this case, the total size of fleet batteries has been selected as 4kWh rated with 50% charging status at initial. Figure-6 shows the load profile before and after BESS installation as well as the State of Charge (SoC) of the battery and charging/discharging profile. It illustrates that the battery is fully discharged at 4:40am and cannot operate afterwards up to next charging status at approximately about 8:00am. As can be seen from the figure, the battery is fully charged within two hours and then cannot operate to consume the PV generated power which caused reverse power flow to grid. The BESS started to discharge at 2:00pm and has fully discharged by about 10:00pm and failed to reduce the maximum demand at 11:00pm. Therefore, the battery cannot operate up to next charging status until about 8:00am the next day. However, the VI rate has been improved due to the partial operation of the BESS and smoothing the load profile, but the LF was not efficiently corrected due to the lack of maximum demand reduction. As discussed earlier in the introduction, the main aim of BESS installation in this paper is to bring maximum benefit of PV generation power based on NET metering scheme for self-consumption. Therefore, the under-sizing of BESS cannot help to bring maximum benefits.

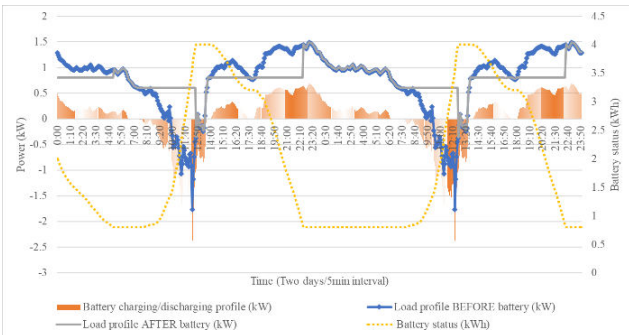

Figure-6. Load profile before and after battery installation.

Table-2. VI and LF indexes before and after BESS.

	Before	After
Variability Index	5.792	2.291
Load Factor	0.516	0.525

Case No. 2, over-sizing battery

In this case, the battery size is oversized compare to the amount of energy consumption of the house. Similar

VOL. 13, NO. 19, OCTOBER 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

to the previous case, the battery starts with 50% status of charge at initial position but now the rated size is set as 12kWh. As can be observed from Figure-7, the battery has significant impacts on load profile after installation and it can operate fora full period of two days while the load profile has been successfully controlled between 0.6 to 0.8kW as targeted. Despite all the significant improvements shown inTable-2 for VI and LF, the size of the BESS in this case seems very big as can be seen from the SoC in Figure-7. It shows that the battery can be charged up to maximum 8.2kW at first day and reduced to 6.3kW at second day. Obviously, by running time series power flow for more days ahead and following battery charging trend, the battery can never get fully charged after a few days and just operates at the low charge level of the battery which is damaging the battery and reducing the lifecycle. On the other hand, the investment cost of the battery with bigger size is also another factor that needs to be considered and can be studied. However, it is beyond the scope of this paper.

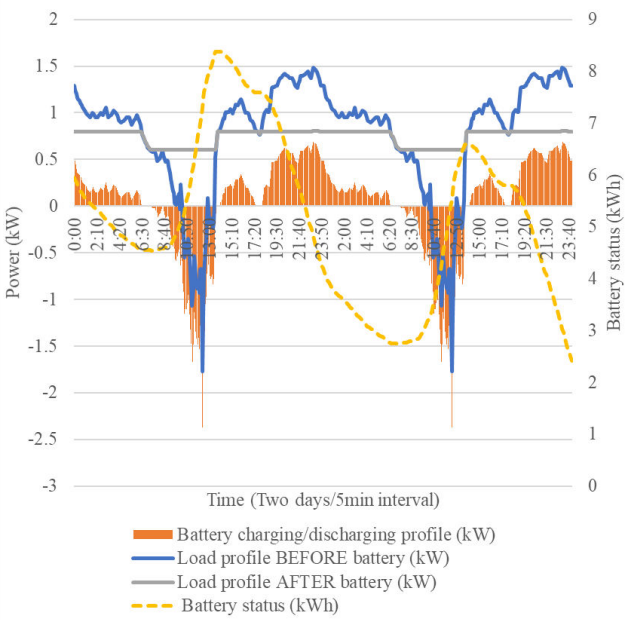

Figure-7. Load profile before and after battery installation for over-sizing battery.

Table-3. VI and LF indexes before and after BESS.

	Before	After
Variability Index	5.792	0.239
Load Factor	0.516	0.919

Case No. 3, non-optimumsizing of battery

Based on the gained experience of previous case studies, running time series power flow for more number of days is very important for tracing the SoC of the battery for longer periods. This case study shows the 10 continuous days of power flow calculation in the case of non-optimum sizing of the BESS. Figure-8 shows the load profile before and after BESS installation with the SoC of battery. It seems that battery sizing is designed properly for the first 5 days of operation, but after the 5th day the battery gets fully charged in the transit domain and could not operate adequately.

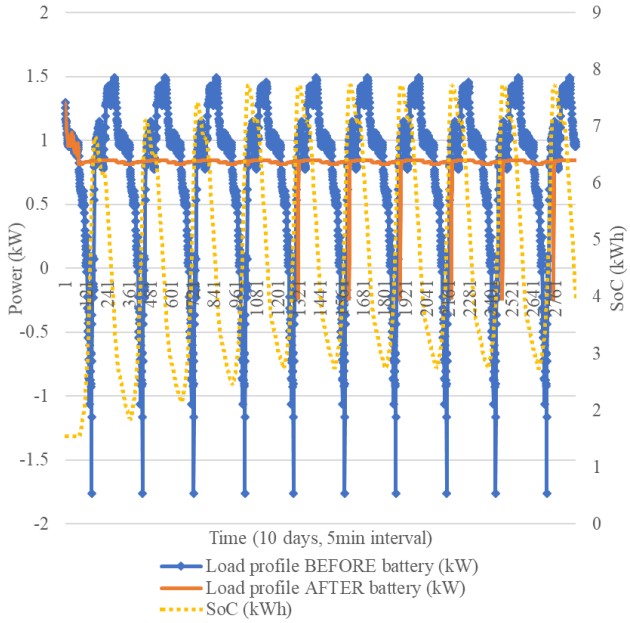

Figure-8. Load profile before and after battery installation.

Case No. 4, optimum sizing of battery

There are different methods of optimum sizing of the battery using either deterministic or stochastic approaches. The optimum size of the battery at the consumer side can help to smoothen the load profile, reduce the maximum demand and avoid reversing power flow for all day of operation as shown in Figure-9. As can be seen from the Figure-9, the SoC of battery for all seven days of operation has the same pattern which enabled the load profile to be smoothed after BESS installation.

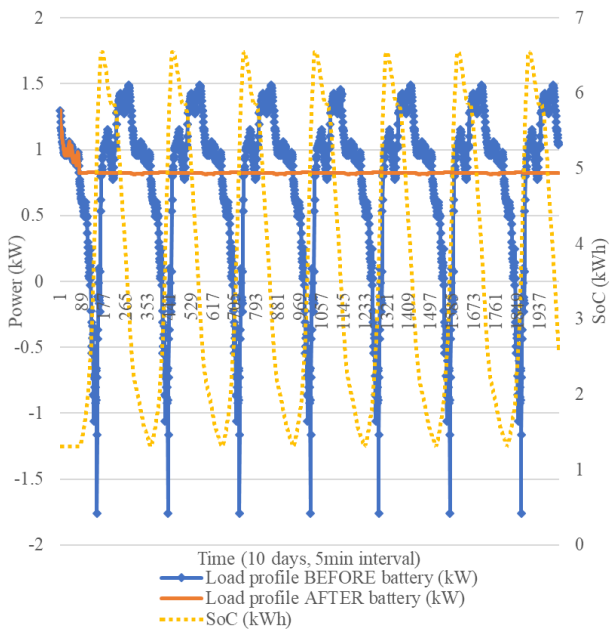

Figure-9. Load profile before and after battery installation for optimum sizing battery.

CONCLUSIONS

The high intermittency of solar PV generation during the cloud-passing days may impose high fluctuation on PV generation profile that has significant negative impacts in power quality. These impacts can be mitigated by integrating the BESS beside the PV generation. Hence, this paper studies four different case studies for BESS sizing at residential consumer's level. It shows the importance and impacts of BESS sizing on the net load profile, more especially during of time of day with high variability PV generation and less power consumption. It is notable to state that utilized power generation and consumption profiles are captured from real installed rooftop PV system. As obtained from the results, the different sizes of BESS have significant impacts on the net load profile of the houses after connecting the battery. The optimum sizing of the battery was able to reduce the maximum demand and smoothen the net load profile by storing the excess generation and consuming at the proper time. Such BESS integration, if implemented effectively, could help the customers to gain the maximum benefits of installed rooftop PV system with this new NET-metering scheme. The LF and VI were shown that significant improvement on the net load profile that can help to utility provider to deliver more reliable power quality to the customers if BESS installed on large scale of the consumers.

REFERENCES

[1] Baharin K.A., Abdul Rahman H., Hassan M.Y., Gan C.K. & Sulaima M.F. 2016. Quantifying variability for grid-connected photovoltaics in the tropics for microgrid application. Energy Procedia, 103(April), 400-405.

[2] Kolbjørn Engeland, Marco Borga, Jean-Dominique Creutin, Baptiste François, Maria-Helena Ramos, Jean-Philippe Vidal. 2017. Space-time variability of climate variables and intermittent renewable electricity production - A review. Renewable and Sustainable Energy Reviews. 79: 600-617.

[3] N. K. Kandasamy, K. J. Tseng, and S. Boon-Hee. 2017. Virtual storage capacity using demand response management to overcome intermittency of solar PV generation.IET Renew. Power Gener. 11(14): 1741-1748.

[4] Lau C. Y., Gan C. K., Baharin K. A. & Sulaima M. F. 2015. A review on the impacts of passing-clouds on distribution network connected with solar photovoltaic system. International Review of Electrical Engineering (I.R.E.E.).10(3): 449-457.

[5] Subramani Gopinath; Ramachandaramurthy Vigna K.; Padmanaban Sanjeevikumar Mihet-Popa Lucian; Blaabjerg Frede; Guerrero Josep M. 2017. Grid-Tied Photovoltaic and Battery Storage Systems with Malaysian Electricity Tariff-A Review on Maximum Demand Shaving. Energies. 10(11): 1884.

[6] N. I. Zolkifri, C. K. Gan, A. Khamis, K. A. Baharin and M. Y. Lada. 2017. Impacts of residential solar photovoltaic systems on voltage unbalance and network losses. TENCON 2017 - 2017 IEEE Region 10 Conference, Penang. pp. 2150-2155.

[7] Y. Liu, J. Bebic, B. Kroposki, J. de Bedout and W. Ren. 2008. Distribution System Voltage Performance Analysis for High-Penetration PV. 2008 IEEE Energy 2030 Conference, Atlanta, GA. pp. 1-8.

[8] Y. Yang, Q. Ye, S. Member, L. J. Tung, and M. Greenleaf. 2017. Integrated Size and Energy Management Design of Battery Storage to Enhance Grid Integration of Large - scale PV Power Plants. 46(c): 394-402.

[9] Y. Ghiassi-Farrokhfal, F. Kazhamiaka, C. Rosenberg, and S. Keshay. 2015. Optimal Design of Solar PV Farms With Storage. IEEE Trans. Sustain. Energy. 6(4): 1586-1593.

[10] Lamberti Francesco & Calderaro Vito &Galdi, Vincenzo & Piccolo, Antonio & Graditi, G. 2015. Impact Analysis of Distributed PV and Energy

Storage Systems in Unbalanced LV Networks. Conference Power Tech. 10: 1-5.

[11] Timur Yunusov, Damien Frame, William Holderbaum, Ben Potter. 2016. The impact of location and type on the performance of low-voltage network connected battery energy storage systems. Applied Energy. 165: 202-213.

[12] K. Veerashekar, P. L. Seta and M. Luther. 2015. Impact of Distributed Battery Energy Storage Systems on Low Voltage Grids with High Amount of Photovoltaics. International ETG Congress 2015; Die Energiewende - Blueprints for the new energy age, Bonn, Germany. pp. 1-8.

[13] Grietus Mulder, Fjo De Ridder, Daan Six. 2010. Electricity storage for grid-connected household dwellings with PV panels. Solar Energy. 84(7): 1284-1293.

[14] A. Busrah, M. T. Au, and M. Mohamad. 2011. End User Load Profile Analysis For Distribution System Planning. In:CIRED 21th International Conference on Electricity Distri. 1(82): 6-9.

[15] TNB. 2007. Electricity Supply Application Handbook Second Edition.