

Battery energy storage system (BESS) design for peak demand reduction, energy arbitrage and grid ancillary services

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ABSTRACT

Renewable Energy (RE) penetration is a new phenomenon in power systems. In the advent of high penetration of RE in the systems, several issues have to be addressed especially when it involves the stability and flexibility of the power systems. Battery Energy Storage System (BESS) has gained popularity due to its capability to store energy and to serve multiple purposes in solving various power system concerns. Additionally, several BESS can be combined to operate as Virtual Power Plant (VPP). This study will involve the design and implementation of BESS for five potential customer sites for the demonstration project and to be possibly integrated into one VPP system. The study is expected to demonstrate bill savings to the customers with BESS due to peak demand reduction and energy arbitrage savings.

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1. INTRODUCTION

The utility world has changed drastically over the last few years. New technologies like Battery Energy Storage System (BESS) and Virtual Power Plant (VPP) have made large inroads into the utility space and no one should want to be left behind. VPP is a combination of renewable sources, Battery Energy Storage System (BESS), solar Photovoltaic (PV) and other interruptible that can supply market needs as a single power plant [1]. VPP is also a concept which includes a network of energy storages or/and distributed generation resources within an area often at the distribution side, linked together to meet utility and consumer challenges such as reduction of maximum demand, energy arbitrage, spinning reserve, frequency regulation, forecasting of sufficient supply to meet the demand, and reducing intermittency of renewable resources. With the current trend of increasing penetration of Renewable Energy (RE) such as solar energy and wind, the use of energy storage is very crucial in ensuring stability and flexibility of grid system. Penetration of RE in the power system is not a concern when the percentage is less than 10% but it will be significant once it reaches 20% from the total power generation [2-3]. To date, Malaysia has approximately 2% of RE generation sources compared to the total generation mix and targets to achieve 20% penetration by 2025 [2].

With higher penetration of RE, the system needs to be ready to solve problems related to stability and flexibility where BESS and VPP can offer such solutions. This paper presents several benefits to cater for this problem including the application of bill savings for the customers which is novel and very new

especially in Malaysian market. Initial idea on the impact of installing BESS in terms of bill savings and serving other applications to the grid will be demonstrated together with the issues related to BESS deployment in Malaysia, which will also be highlighted.

2. BACKGROUND

BESS has a wide range of applications covering from generation and transmission up until behind-the-meter application. For generation side application, BESS can be used for spinning reserve, frequency regulations, black start, energy arbitrage and even as an alternative to peaking plants. For transmission and distribution sides, BESS can contribute as an asset deferral or congestion relief to the utility companies. Finally, for the behind-the-meter application, BESS can be used to fully optimise the power from solar generation either for commercial, industrial or residential customers [4-6].

There are few types of normally known battery types in the market namely Lead Acid, Sodium Sulphur, Lithium-ion and Flow Battery [3]. Each and every type have their own unique characteristics. Lead acid batteries are considered a pioneer in supplying batteries for power system. Lithium-ion is attaining popularity due to be competitiveness in pricing. Lithium-ion battery costs have declined 80% in the last five years and expected to decline 47% Compound Annual Growth Rate (CAGR) in the next five years [6].

3. BATTERY ENERGY STORAGE SYSTEM (BESS) APPLICATIONS

A study conducted by the Rocky Mountain Institute summarised of up to 13 potential applications which could be offered by the BESS. The segments are illustrated in Figure 1.

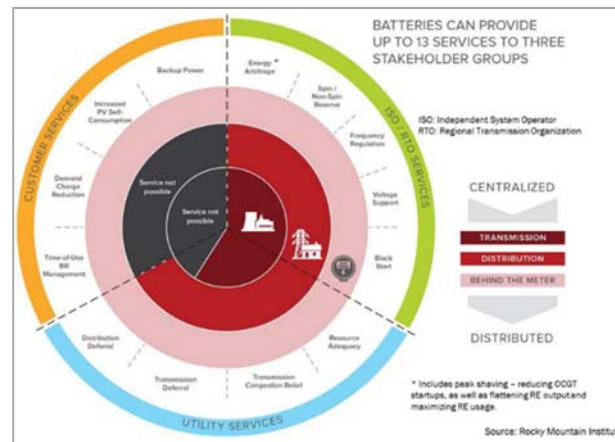


Figure 1. Various possible application of BESS [4]

3.1. BESS for grid system operator (GSO) applications

For grid application, BESS can be used for Spinning Reserve, Frequency Regulation, Black Start, and Energy Arbitrage and for output smoothing application for Renewable Energy [7-11]. For spinning reserve, this application can contribute savings to the total generation cost. This can be achieved by releasing spinning reserve capacity from base load generations and replacing with BESS. By maximising the base load generation that normally coming from the generations from lower tier of the merit order, savings can be achieved from lower generation cost from natural gas which is in the higher tier of the merit order [12].

For Frequency Regulation application of BESS, it can be used to maintain frequency level of the system. The advantage of BESS in terms of fast response to correct frequency of the grid system makes it a good candidate for this application [13-15]. BESS can also be an alternative for generation black start. For this application, it should be coupled with other application for the economics to work as this application has low utilisation of charging and discharging the battery. Another possible application for BESS is for Energy Arbitrage. This is possible when BESS is charged during off-peak period and discharge during peak period. This will provide savings to the total generation cost and finally passed on to the customers via lower tariff. In the case for Peninsular Malaysia this savings can be passed on to customers via the Imbalanced Cost Pass-Through (ICPT) mechanism which is revised twice a year to reflect actual generation cost [16]. Another

common application of BESS is for Renewable Energy integration. Excess RE generation in the system creates natural demand for BESS as it offers stabilisation effect to the ‘duck curve’ effect to the system as illustrated in Figure 2.

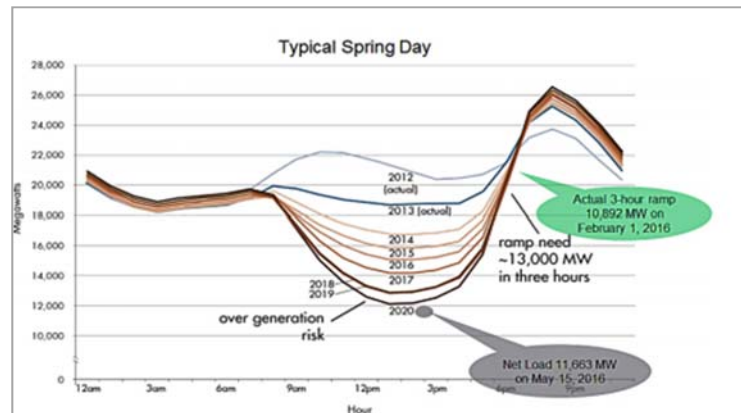


Figure 2. Various possible application of BESS [17]

3.2. BESS for utility applications

For this application there are few main areas of possible application of BESS namely transmission and distribution asset deferral, and congestion relief. For this possible application, with the kind of capital cost needed for BESS to replace conventional have to be at a reduced rate compared to current rate to ensure positive economics to the investment.

3.3. BESS for customer applications

BESS for Behind-the-meter (BTM) application, it can be considered across several services. This includes Time-of-use (ToU) bill management, to be coupled with solar rooftop and to enhance the self-consumption capability, to be part as demand management and finally as a back-up power. At this point of time, the values have to be stacked in order to achieve positive economics to the investments. The price of BESS is estimated to fall and reach at the level where the project will be viable and offer a greater savings to the customers. Another possible viable case is when there is a bigger gap for ToU tariffs. For Malaysian customer tariff, BESS for BTM is more sensible for investments for customers with peak and off-peak tariff coupled with demand charge. With the installation of BESS, it is expected to give savings to customers' bill taking advantage of peak demand reduction and energy arbitrage effect from BESS operation. [18-21].

4. INCENTIVE BASED REGULATIONS

Starting from 1st January 2014, Malaysia has embarked into Incentive Based Regulations (IBR) for tariff design and management. This regulation is a structured tariff setting mechanism with fair reward to the utility for a certain quality service supplied to the customers. This regulation that has been adopted by TNB consists of three main elements, which are the Base Tariff, Imbalance Cost Pass Through (ICPT) and Performance Indicators. This tariff setting mechanism is regulated by Energy Commission (EC) of Malaysia to ensure efficient tariff is charged to the customers.

4.1. Base tariff

The electricity tariff review for Malaysia effective on 1st January 2014 is different from previous tariff reviews in Malaysia. The new tariff is the Base Tariff for IBR first regulatory period in Malaysia, starts from 2015 to 2017 for Regulatory Period 1 (RP1) and from 2018 to 2020 for Regulatory Period 2 (RP2). The average tariff increase for Base Tariff for Peninsular Malaysia for RP2 is increased from RP1, 39.45 sen/kWh to 38.53 sen/kWh, an increase of 2.4% or 0.92 sen/kWh, which mainly contributed by Single Buyer Generation cost. The increase in tariff is to cover the rising fuel cost namely piped gas, Liquid Natural Gas (LNG) and coal.

4.2. Imbalance cost pass through (ICPT)

ICPT mechanism is a part of the whole IBR implementation in Malaysia. ICPT was designed to ensure that the cost related to fuel and other generation cost can be passed through to customers. ICPT rate is revised twice yearly to reflect actual generation cost to be passed through to customers in terms of rebate or surcharge in customers’ monthly bill.

4.3. Enhanced time of use tariff (EToU)

As an extension of ToU scheme, Energy Commission (EC) launched EToU in 2016. Peak time zone under EToU is reduced to 4 hours from the existing 14 hours. Mid-Peak zone of 10 hours is introduced for Energy and Demand Charges at rates lower than the current peak rates. Off-peak zone maintained for 10 hours as shown in Figure 3. EToU is offered on an optional basis to Commercial and Industrial customers connected at Low Voltage, Medium Voltage and High Voltage. All customers who wish to enroll for ETOU scheme must enter into an agreement with TNB [22].

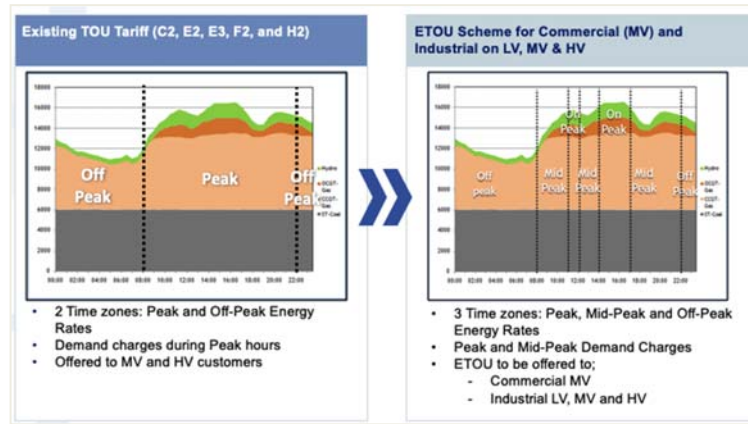


Figure 3. Enhanced time of use (EToU) Mechanism

5. LOAD PROFILE ANALYSIS

In this study, five customers were selected. The basis of selection is based on the tariff category. Customers under tariff category with peak demand charge and peak and off-peak tariff. These types of customers are anticipated to give benefit in terms of bill savings to the selected customers. The selected customers for the demonstration project are as follows. A research centre, a commercial customer, education campus, industrial customer and a university.

For the purpose of the study, half-hourly load profile of potential customers was extracted for a year and the peak demand and load pattern were analysed. Half-hourly load profiles were tabulated and illustrated in Figure 4, Figure 5, Figure 6, Figure 7, and Figure 8. Each and every figure for Figure 4, Figure 5, Figure 6, Figure 7, and Figure 8 is showing different profile of load data depending on the type of energy consumption of each customer type.

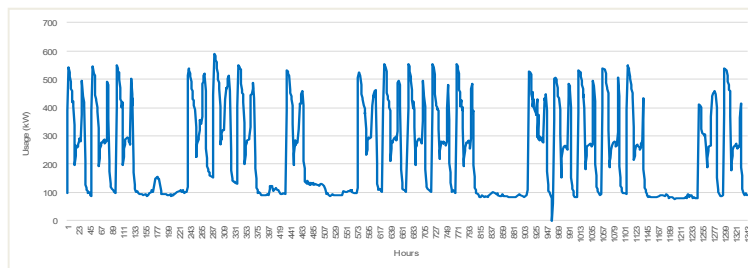


Figure 4. Typical monthly load profile for a research centre

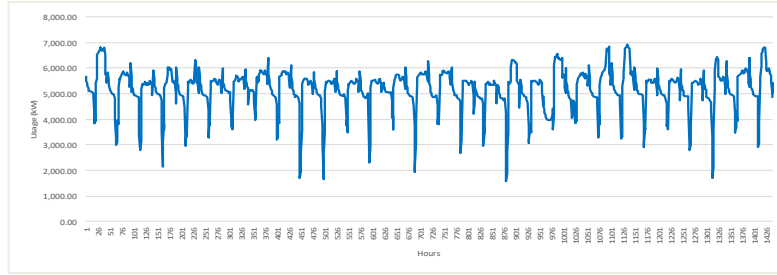


Figure 5. Typical monthly load profile for a commercial customer

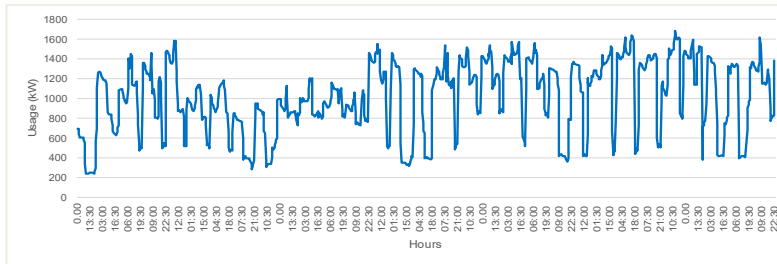


Figure 6. Typical monthly load profile for an education campus

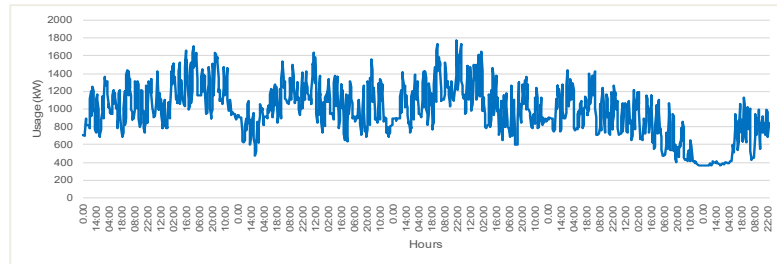


Figure 7. Typical monthly load profile for an industrial customer

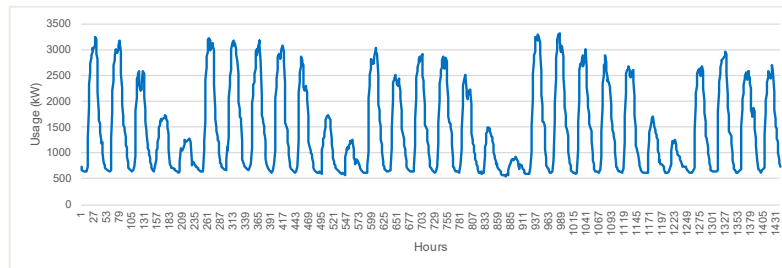


Figure 8. Typical monthly load profile for a university

6. TECHNICAL DESIGN

From the load profile, peak demands of each site can be determined and calculations on the targeted savings due to peak demand reductions is done using (1) and (2). Power Converter System (PCS) and BESS can be designed accordingly based on desired peak reduction.

$$S_{PCS} = PD_{hist} (MW) - PC_{target} (MW) \tag{1}$$

$$S_{BESS} = \sum PD_{hist} (MW) - PC_{target} (MW) \times Hour \quad (2)$$

Where:

- S_{PCS} : Desired PCS size (MW)
 S_{BESS} : BESS Size (MWh)
 PD_{hist} : Peak Demand for half-hourly slot
 PC_{target} : Target Peak Reduction

For the capital cost of BESS, it is determined by using the following calculation [23]:

$$C_{BESS} = \lambda_{pwr} \times S_{pwr} + \lambda_{cap} \times S_{cap} \quad (3)$$

Where:

- λ_{pwr} : Storage Capital Cost for Power BESS (RM/MW)
 S_{pwr} : Power Capacity
 λ_{cap} : Storage Capital Cost for Energy BESS (RM/MWh)
 S_{cap} : Energy Capacity

Degradation and system losses have to be determined in the design process. This is to ensure that expectations of the BESS performance are considered and calculated in the design stage. The cost of degradation and losses can be computed using (3) [23].

$$C_{deg,t} = (S_{loss,t} + S_{charge} + S_{discharge}) \times \lambda_{deg} \quad (4)$$

Where:

- $C_{deg,t}$: Cost of degradation and losses
 $S_{loss,t}$: Energy to cater losses
 S_{charge} : Energy used to charge BESS during off-peak time
 $S_{discharge}$: Energy used to discharge BESS during peak time
 λ_{pwr} : Cost of degradation (RM/MWh)

Studies were conducted on the load profile analysis, comparison on before and after BESS installation and VPP integration using HOMER software. Figure 9 shows a sample of design analysis in HOMER. Analysis conducted on how each site can benefit from BESS installation, either for the improvement of their electricity consumption, participation for grid ancillary service or energy trading between sites for Virtual Power Plant (VPP) mode of operation [24]. The direct benefit to the customers is the reduction of maximum demand and the energy arbitrage of Time of Use (ToU) tariff. With the possibility of solar plant connected to the customer, energy storage operator can store the energy directly from solar, as an alternative to charging the battery using off-peak tariff. For the system operating in a VPP mode, it can be used to serve the grid ancillary service such as frequency regulation.

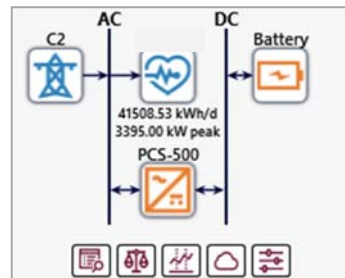


Figure 9. Sample design of BESS system in HOMER software.

For peak demand reduction, for example for a customer under C2 tariff, the maximum demand charge is RM 45.10 per month. Charging BESS during the low peak period and discharging during peak demand time will potentially avoid or reduce the peak demand charge. For energy arbitrage, the BESS can be charged during the peak hours and discharged during off-peak hours. The savings can be harnessed and customers will experience bill reduction. For instance, for C2 customers in Table 1, charging at off-peak hour

cost 22.40 sen/kWh and discharges at peak hour rate of 36.50 sen/kWh. The difference of 14.1 sen/kWh can be achieved almost immediately.

From the load profile analysis of several potential sites, it is shown that customers with peak and off-peak demand together with the maximum demand charge will enjoy most savings with BESS installation. This also results in a lower payback period to the investments.

Table 1. Tariff Rates for Malaysian Commercial Customers

Tariff Category	Current Rates
Tariff B – Low Voltage Commercial Tariff	
First 200kWh (1-200kWh) per month	43.5 sen/kWh
For the next kWh (201 kWh onwards per month)	50.9 sen/kWh
The minimum monthly charge is RM7.20	
Tariff C1 – Medium Voltage General Commercial Tariff	
For each kilowatt of maximum demand per month	30.3 RM/kW
For all kWh	36.5 RM/kWh
The minimum monthly charge is RM 600	
Tariff C2 – Medium Voltage Peak/Off-Peak Commercial Tariff	
For each Kilowatt of maximum demand per month during the peak period	45.1 RM/kW
For all kWh during the peak period	36.5 sen/kWh
For all kWh during the off-peak period	22.4 sen/kWh
The minimum monthly charge is RM 600	

7. BESS FOR ANCILLARY SERVICES (FREQUENCY REGULATIONS)

For grid application, BESS can be used for Spinning Reserve, Frequency Regulation, Black Start, Energy Arbitrage and for power output smoothing application for Renewable Energy. For spinning reserve, this application can contribute savings to the total generation cost. This can be achieved by releasing spinning reserve capacity from base load generations and replacing with BESS. By maximising the base load generation that normally comes from the generations from lower tier of the merit order, savings can be achieved from lower generation cost from natural gas which is in the higher tier of the merit order.

For Frequency Regulation application of BESS, it can be used to maintain the frequency level of the system. The advantage of BESS in terms of fast respond to correct frequency of the grid system makes it a good candidate for this application. BESS can also be an alternative for generation black start. For this application, it should be coupled with other application for the economics to work as this application has low utilisation of charging and discharging the battery.

Another possible application for BESS is for Energy Arbitrage. This is possible when BESS is charged during the off-peak period and discharge during the peak period. This will provide savings to the total generation cost and finally passed on to the customers via lower tariff. In the case for Peninsular Malaysia, this savings can be passed on to customers via the Imbalanced Cost Pass-Through (ICPT) mechanism which is revised twice a year to reflect actual generation cost. Another common application of BESS is for Renewable Energy integration. This application is crucial when the penetration of RE in the power system. As Malaysia is targeting to achieve 20% RE by 2025, it is very prudent to invest in BESS for the stability of the grid system.

BESS is also possible to serve as one of the ancillary services for frequency regulation that can be offered to Grid System Operator (GSO). Malaysia Grid Code (MGC) [25] states that primary response is defined as the automatic response over the period from zero to ten seconds and must be sustained for twenty seconds. While secondary response must be available by thirty seconds from the time of frequency change to take over from the primary response and must be sustainable for at least thirty minutes [25].

Degradation and system losses have to be determined in the design stage. Losses for charging and discharging has to be considered as a round trip efficiency of the BESS.

For the deployment of the project, the integration of software and hardware of the system will take place and will take into consideration all policy, standards and licensing required by Energy Commission (EC). Finally, evaluation of the system will take into consideration the savings of electricity bill and contribution to grid frequency regulation.

8. CHALLENGES AND ISSUES

Among the challenges and issues of project deployment is to determine the right service for the BESS and determining the right business model for the BESS. The proposed business model is just to cater

for peak demand reduction and energy arbitrage which can give savings to customer bill. The most economical way in designing BESS is to address few applications for instance benefit stack with grid ancillary services. With this, the benefit of the BESS installation will be more significant for instance shorter payback period or higher return on investment (ROI).

For ancillary services in Malaysia, traditionally the rate for these services is bundled under the Power Purchase Agreement (PPA) of each power generator, a new policy and guideline are needed to incentivize BESS in providing the appropriate incentive for the services to the grid. For grid application, BESS can be used for Spinning Reserve, Frequency Regulation, Black Start, Energy Arbitrage and for output smoothing application for Renewable Energy and if each of these services is remunerated accordingly, it will motivate deployment of BESS for these purposes.

For any connection to TNB system, Power System Studies (PSS) is required to determine the connection scheme, the load flow including the impact any mitigation plan for power system stability and to avoid reverse power flow to the distribution system. Based on Malaysia Distribution Code, any Distributed Generation less than 30MW is required to disconnect from the distribution system in the event of loss of incoming supply to avoid any unintended islanded operation.

For standard and policies, it still not established for the implementation of BESS projects. For instance, safety standards for utility-scale batteries have not been established. At the moment, it is using the safety standard for small scale batteries IEC 62133 [26]. In term of communication, installations of BESS and VPP have to comply to TNB's communication protocol and cybersecurity policies i.e: IEC 60870 addressing telecommunication issues. This is to ensure data security as all data especially the communication and control of BESS is linked to Grid System Operator (GSO) and is classified as critical and very sensitive in terms of data security. Most of data communications and control are related to charging and discharging from BESS to cater the targeted applications.

9. RESULTS AND DISCUSSION

The project is to demonstrate the technical and economic feasibility of BESS installation. It is also designed to demonstrate VPP to serve grid application such as frequency response. With the right optimized sizing of BESS and PCS, some customers are able to enjoy as low as 7 years of pay-back period, but some customers will have higher payback period depending on the load pattern. The payback period is potentially reduced with the anticipation of price reduction of BESS. Based on price projection by Bloomberg New Energy Finance, the price of BESS is reducing at an average rate of 5% per year [27]. Results on benefit are tabulated in Table 2.

Table 2. Site tariff type and benefit

No	Site	Tariff Type	Benefit
1	Research Centre	Medium Voltage Peak/Off-peak Commercial Tariff C2 Tariff	Peak demand cut Energy Arbitrage (Peak and Off-peak) Grid Frequency Regulation
2	Commercial Customer	Medium Voltage Peak/Off-peak Commercial Tariff C2 Tariff	Peak demand cut Energy Arbitrage (Peak and Off-peak)
3	Education Campus	Medium Voltage Peak/Off-Peak Commercial Tariff C2 U Tariff	Peak demand cut Energy Arbitrage (Peak and Off-Peak)
4	Industrial	Medium Voltage Peak/Off-peak Commercial Tariff C2 Tariff	Peak demand cut Energy Arbitrage (Peak and Off-Peak)
5	University	Medium Voltage Peak/Off-peak Commercial Tariff C2 Tariff	Peak demand cut Energy Arbitrage (Peak and Off-Peak)

Load profile after installation and the effect of peak demand reduction on the highest load month are shown in Figure 10, Figure 11, Figure 12, Figure 13, and Figure-14, where the red lines indicated that the peak has been cut by using BESS:

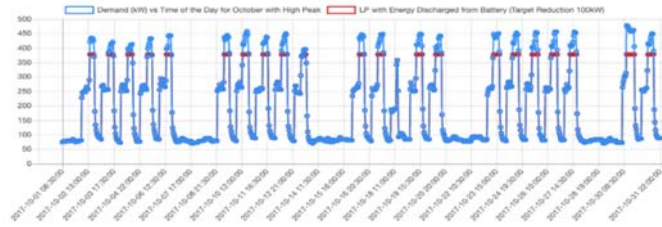


Figure 10. Typical monthly load profile for a research centre customer after BESS installation



Figure 11. Typical monthly load profile for a commercial customer after BESS installation

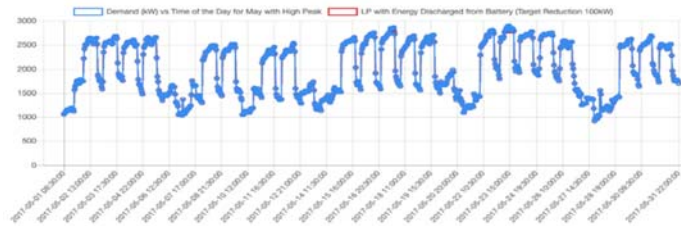


Figure 12. Typical monthly load profile for an education campus after BESS installation

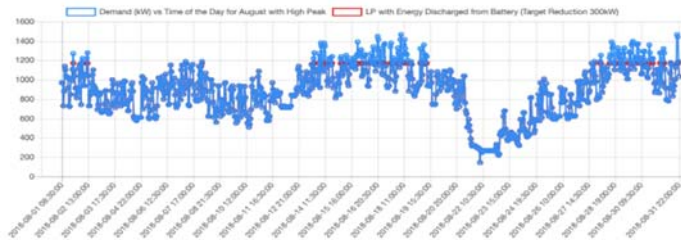


Figure 13. Typical monthly load profile for an industrial customer after BESS installation

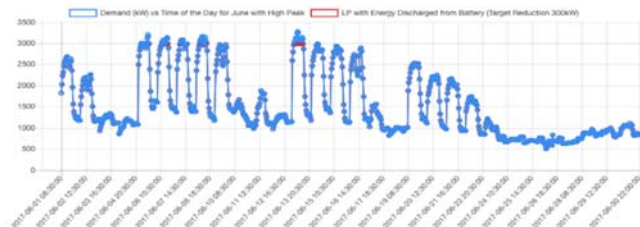


Figure 14. Typical monthly load profile for a university after BESS installation

10. CONCLUSION

In conclusion, with the installation of BESS to selected customers with peak demand charge and also peak and off-peak tariff characteristics, it will benefit customers in bill savings. Additionally, the economics of BESS installation will improve with revenue stack from other ancillary services such as frequency regulations. In the country of Malaysia, such market for ancillary services is still not available because all ancillary services are embedded in the Power Purchase Agreement (PPA) rates. With this study, it has demonstrated benefits by BESS installation which is bill savings to the customers that can be the motivation for the implementation of ancillary service market remuneration.

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BIOGRAPHIES OF AUTHORS



Wan Syakirah Wan Abdullah was born in Petaling Jaya, Selangor Malaysia on 6th May 1980. She obtained her Degree in Electrical Electronics (2002) and Masters in Electrical Engineering (2012) from Universiti Tenaga Nasional Berhad, Malaysia. She is currently the Head of Business Development 2 of TNB Renewables Sdn. Bhd., a wholly owned subsidiary of Tenaga Nasional Berhad. Her experience in Power System covers generation scheduling, outage management, power system security, forecasting and Incentive Based Regulations (IBR) the tariff setting mechanism for Malaysia and recently involved in Development of Renewable Energy in Malaysia including Solar, Biomass, Biogas, Mini Hydro and Battery Energy Storage System. She is a registered Professional Engineer under Institute Engineers Malaysia (IEM) and Board of Engineers Malaysia (BEM).



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