An Analysis and Comparison of Battery Size Selection and Economic Worthiness of Two Industrial Plants based on Electricity-generating from Solar Power for Self-Consumption

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Received: 02/06/2021, Accepted: 22/06/2021

Abstract

Industrial plants in Thailand have invested in the installation of the system of electricity-generating from solar energy for self-consumption. Sometimes, it has the excess power supply which could have a reverse power flow to the electrical system of the Provincial Electricity Authority. This is because some industrial plants install the electrical generation system which is more than the actual load or some periods of time that an industrial plant reduces energy uses. Consequently, this influences lack of power quality and its characteristic does not comply with power network system interconnection code of the Provincial Electricity Authority. However, it can be solved by the installation of appropriate battery sizes.

The purposes of this paper are to reduce reverse power generating from solar PV of industrial factory to PEA's system and to decrease energy losses in term of self-consumption. This article analyses energy losses of electrical generation system from solar PV power, selection of appropriate battery size and its economic worthiness. Data from two industrial plants are analyzed based on electrical consumption patterns. The industrial plant 1 uses electricity during weekdays which is more than weekend whereas the industrial plant 2 uses an amount of electricity during weekend and weekdays which is almost the same. The analysis results show that factory 1 should select battery size of 34 kWh and factory 2 is able to choose battery size of 143 kWh or 268 kWh. This is because it can reduce impacts on power quality due to reserve power and strengthen system stability of the Provincial Electricity Authority. Also, it can generate increased revenue to the organization by selling the electricity surplus.

Keywords:

Battery, Economic Worthiness, Electricity Generating, Solar Energy

1. Introduction

Electricity generation from renewable energy sources has gradually increased in Thailand due to the government policies encouraging alternative energy generation and the purchase of electricity from the private sector producers. Solar power generation [1] is quite high because of the ease of construction and installation of solar power plants as well as the high economic feasibility of such projects [2, 3].

However, a large number of solar power plants connecting to the Provincial Electricity Authority (PEA) distribution network can affect the power quality of the network system [4, 5, 6, 7]. Solar power plants can generate electricity only during daytime and the generation can be unstable. The installation and operation of battery storage can help make more stable and reliable electricity generation from solar power plants [8, 9, 10]. An economic feasibility analysis of the use of battery storage can help maximize the utilization of a battery storage system [11, 12].

Solar power plants operate mainly to sell electricity to grid, however, generation for self-consumption is now rising. Some operators have installed solar photovoltaic (PV) plants that are of inappropriate capacity and standards as they are larger than the targeted load. This causes reversed power flow to the distribution network, and this violates the PEA regulations on power network system interconnection code B.E.2016 [13]. Section 7.1.15 of the code states that "A power consumer owning a generator must design a system that do not dispatch power current into the power network system, nor over-consume the power which may negatively affect PEA power network system as well as other power consumers".

The large amount of surplus and incontrollable energy from a solar PV system affects the power quality and results to power losses in the network system. The solution to this problem is to install a battery storage system that is suitable to both the solar PV system and the actual loads [14, 15]. However, the methodology to find out the suitable size of battery storage, reduce the losses and achieve economic feasibility, differ for each system depending on factors such as solar irradiance, installed capacity of the solar PV system, and the load characteristic.

2. Study Objectives

The study aimed to select appropriate battery storage size by analyzing and comparing system losses, and conducting economic feasibility study in terms of payback period (PBP) and internal rate of return (IRR) of solar power generation for self-consumption. The study targeted two industrial plants which have different load characteristics. Modeling studies and analysis were conducted using the simulation software "DIgSILENT Power Factory" to calculate the system losses and the battery storage sizes.

The expected results of the study included the calculations and analysis of the power losses, battery storage sizes, and the economic feasibility of the systems of the two industrial plants. The results were shown in both graph and numeric formats. The analysis was expected to show the reduction of losses in the plants generating electricity for self-consumption, to check if the interconnection point had complied with the PEA interconnection code, and if there was reduction of power quality the distribution network.

3. Experimental Study Approach

3.1. Methodology

The methodology consists of the following steps:

(1) Modeling the electrical system of factories 1 and 2 using the simulation software

(2) Inputting the parameters of the individual component such as the solar PV generation profile and the load characteristic of the factories

(3) Analyzing the energy losses by calculating the reverse power to the PEA network from factory during the weekdays and weekends for the base case, which is with no battery installation

(4) Specifying various case studies by varying battery storage system sizes, and then calculating the IRR and payback period (PBP) for each case, this is done for each of the factory as below:

(4.1) Case 1: Assign the size of the battery storage system equal to the 100% of energy loss (E_{LOSS}) during the weekdays. When there is surplus generation from the solar PV system, the battery storage system starts charging and storing energy. The battery storage system can initiates discharging energy to PEA distribution network, in peak and off-peak period.

(4.2) Case 2: Assign the size of battery storage system equal to the 100% of energy loss (E_{LOSS}) during the weekend. When there is surplus generation from the solar PV system, the battery storage system starts charging and storing energy. The battery storage system initiates discharging energy to PEA distribution network in both peak and off-peak periods.

(5) Analyzing and comparing the two cases in terms of energy losses and economic feasibility.

The flow chart and criteria of simulation presents in Fig. 1.

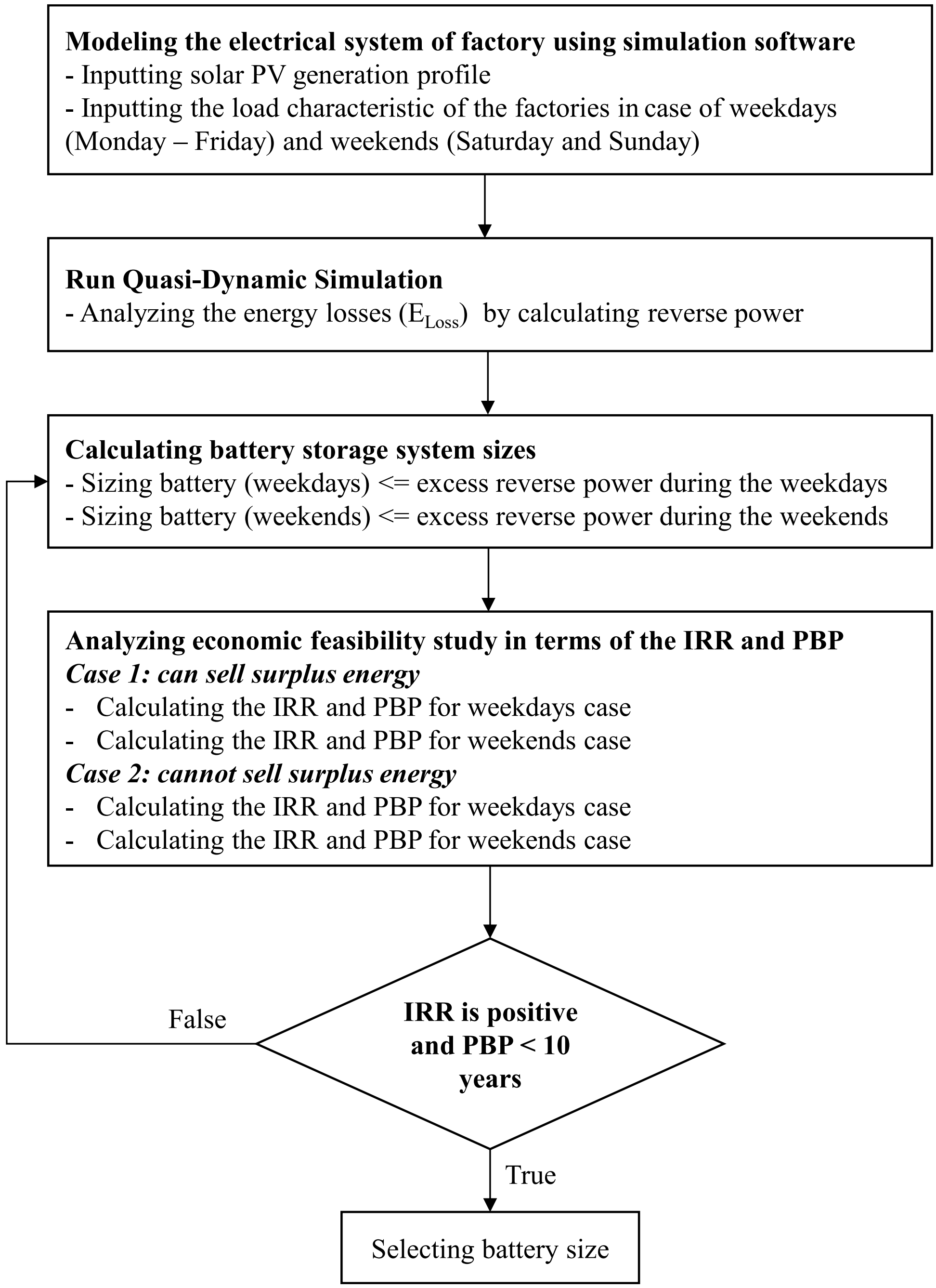


Fig. 1 flow chart and criteria of simulation.

3.2. Simulation software

This research analyzed and simulated the PV power systems using the "DIgSILENT Power Factory software", an international power system analysis software which can analyze the impact of renewable energy resources on the power network. The software was used to model the operations of the solar PV plants of the two factories, which were interconnected to the PEA distribution network.

3.3. Data analysis

Internal industrial plant model

The simulation model for factories 1 and 2 are shown in Fig. 2 and 3, respectively.

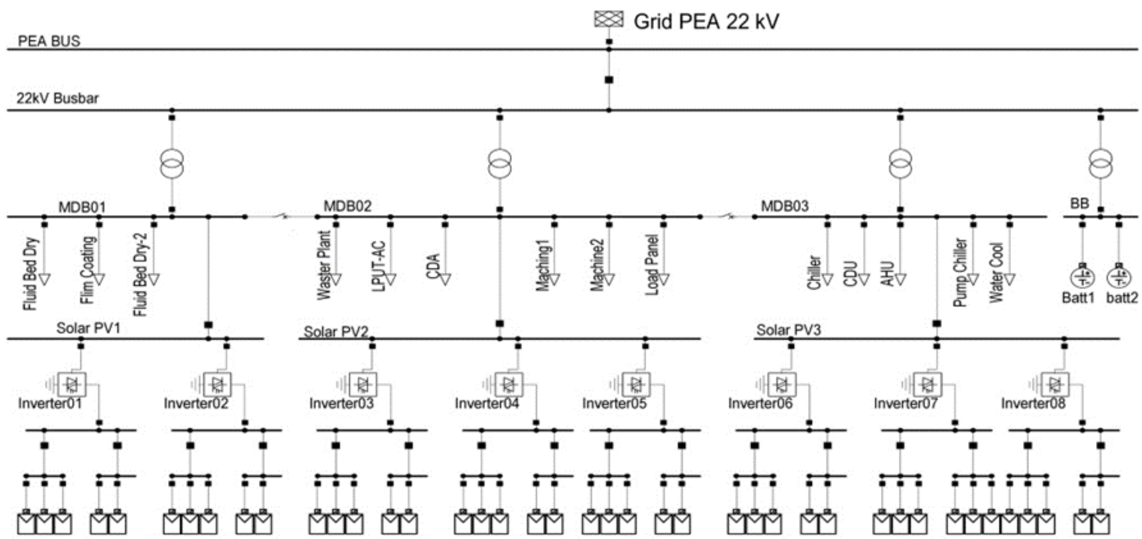


Fig. 2 Factory 1 simulation model located in Kokkham, Muaeng district, Samutsakorn province.

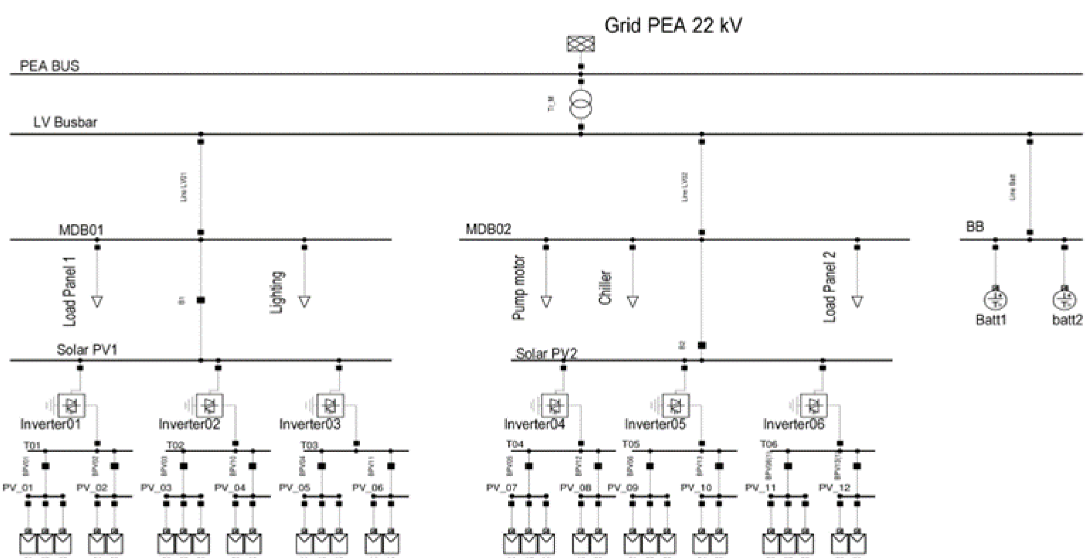


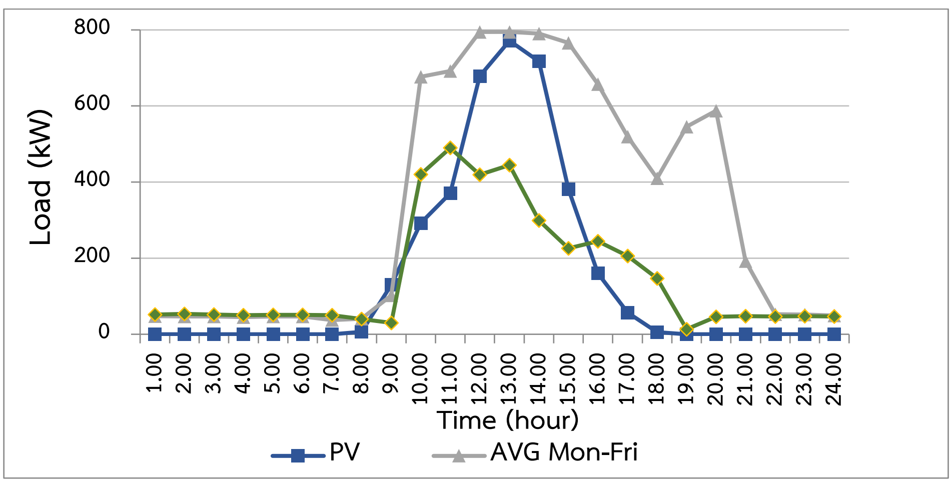
Fig. 3 Factory 2 simulation model located in Mabtaphud, Muaeng district, Rayong province.

3.4. Industrial factory data

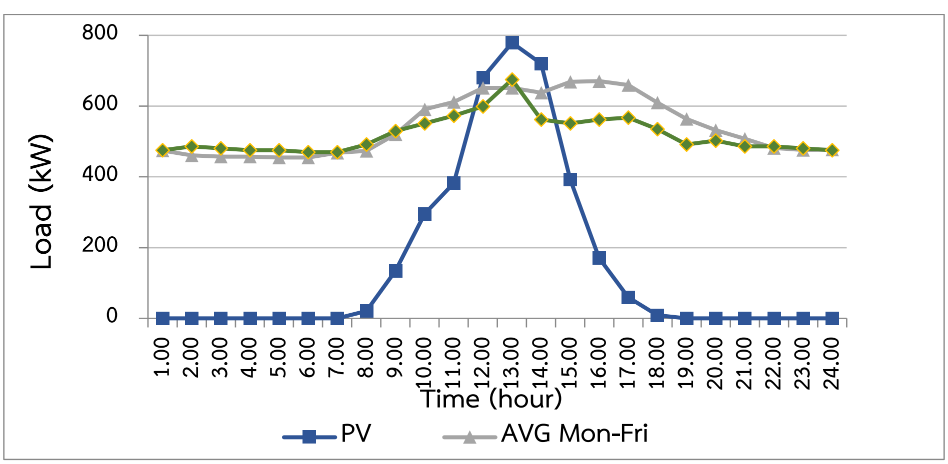
The installed capacity of the solar PV system for factory 1 is 995.715 kWp, and for factory 2 is 978.75 kWp. The solar PV system supplies electricity mainly for internal consumption but are connected through inverters to the PEA distribution network for supplying the excess generation to the network.

3.5. Industrial factory loads

Both factories were using the electricity "Time of Use (ToU)" rate. This research collected load characteristics for one week to cover the peak/off-peak periods during the weekend and weekdays. The data showed that the average load of factory 1 on weekdays (Monday - Friday) are higher than on weekends (Saturday - Sunday). The peak load occurred between 9 a.m. to 7 p.m. as shown in Fig. 4 (a). On the other hand, the average load of factory 2 was almost the same during the weekdays and the weekend. Factory 2 had a gradually increasing load during the day with the peak load occurring between 8 a.m. and 5 p.m. as shown in Fig. 4 (b).



(a)



(b)

Fig. 4 Weekly solar PV generation and loads (a) factory 1 (b) factory 2.

3.6. Battery energy storage system (BESS)

Lead-acid batteries were chosen for both factories. This battery storage system has 80% efficiency and 5 to 15 years lifetimes. The size of the battery storage system was determined based on the size of the losses of the factories, and the size was made either equal or larger than the size of the overall power losses.

3.7. Losses calculation

Losses were calculated based on the energy generation from the solar PV systems which exceeded the loads. The generation from the installed capacities of the solar PV systems were bigger than the actual loads as shown in Figures 4 (a) and 4 (b). The surplus energy flow reversely back to the PEA distribution network resulting to energy loss for the factories, as there was no payment for this electricity supplied back to the network. The energy loss is calculated using equations (1) and (2) below.

$$E_{LOSS} = E_{PVP} - E_{USE} - E_{SystemLoss} \tag{1}$$

$$E_G = \frac{E_{LOSS}}{E_{USE}} x100 \tag{2}$$

where:

E_{LOSS}	=	energy loss in kWh
E_{PVP}	=	energy generation of solar PV system in kWh
E_{USE}	=	energy consumption of factory in kWh
$E_{SystemLoss}$	=	internal system loss of factory in kWh
E_G	=	proportion of energy loss to energy consumption in percentage

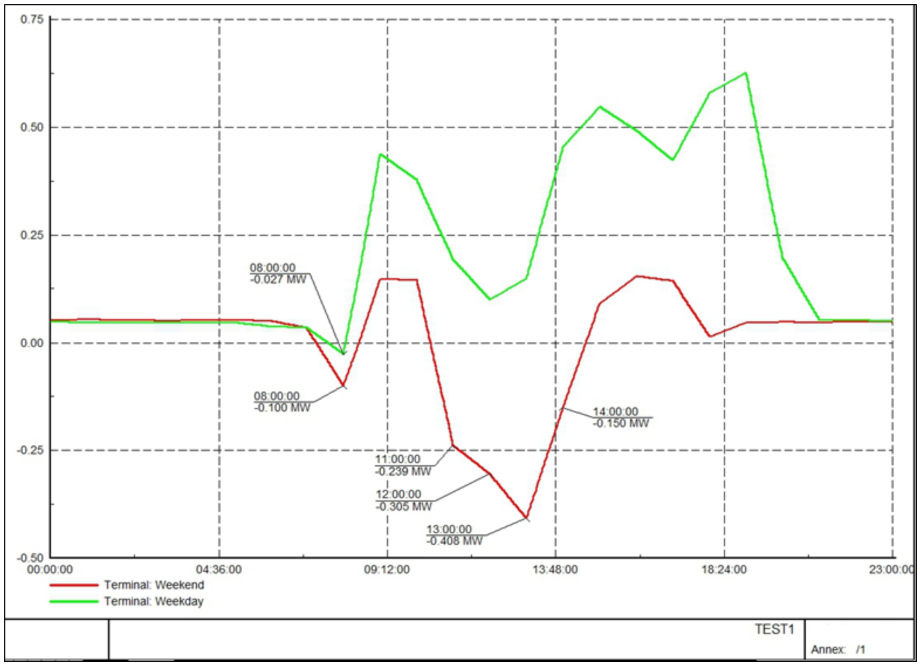
Energy losses would determine the appropriate size of battery storage for the system.

3.8. Economic analysis

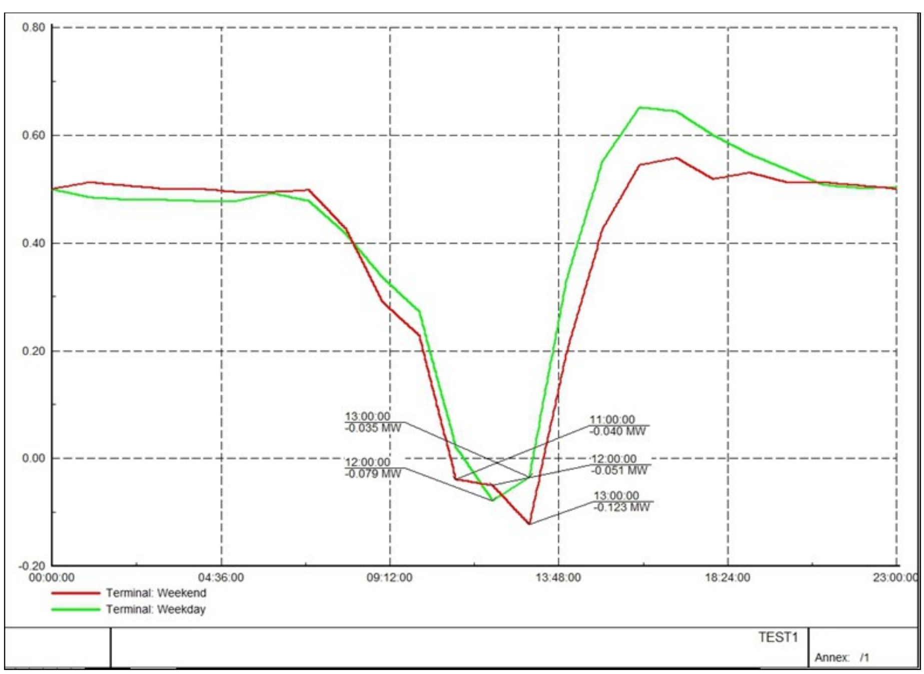
The assumptions made to calculate the IRR and payback period are shown in Table 1 below.

Table 1 Electricity tariff, electricity selling tariff, battery storage cost.

Description	Amount	Unit
Electricity tariff		
Peak period	4.2097	Baht/kWh
Off-peak period	2.6295	Baht/kWh
Electricity selling tariff	1.00	Baht/kWh
Battery storage cost	6,000	Baht/kWh
Project life time	10	year



(a)



(b)

Fig. 5 Energy loss versus time period of (a) factory 1 (b) factory 2.

4. Results

4.1. Energy losses and battery size selection

For factory 1, the excess energy production from the PV system were at 8 a.m. in weekdays, and at 8 a.m. and during 11 a.m. to 2 p.m. in weekends as shown in Figure 5 (a). As this excess production flowed reversely back into the network, this were energy losses of the factory. Table 2 presents the total energy losses and the calculated size of the battery storage system of 80% efficiency, needed to store the entire energy losses from factory 1.

For factory 2, the excess energy production from the PV system were between 12 a.m. and 1 p.m. on weekdays, and during 11 a.m. to 1 p.m. on weekends as shown in Figure 5 (b). The total energy losses and battery size are illustrated in table 2. The capacity of the battery storage system is dependent on the total energy loss and should be able to store the entire energy generated for the factory on the total energy losses.

Table 2 Energy loss (E_{LOSS}) and battery storage size.

	Factory 1 Solar PV 995.715 kW_p		Factory 2 Solar PV 978.75 kW_p	
	Weekday	Weekend	Weekday	Weekend
E_{LOSS} (kWh)	27	1,202	114	214
E_G (%)	0.34	33.60	0.88	1.72
Battery size (kWh) at 80% efficiency	34	1,503	143	268

4.2. Economic analysis

<u>Case 1: Factories cannot sell solar PV system excess generation to the network system.</u>

<u>Factory 1:</u>

In the case where the factory installs a 34 kWh battery storage system to store 100% of the electricity generated during weekdays, the economic feasibility analysis shows that the IRR is 12.8% and payback period is 5 years if the battery storage system discharge during peak periods. For off-peak period discharge, IRR is about 4.8%, while payback period is 7 years.

In the case where the factory installs a 1,503 kWh battery storage system to store 100% of electricity generated during weekends, the IRR is -14.0% and payback period is 25 years, when the batteries discharge in peak periods. The IRR is reduced to -14.4%, while the payback period is extended beyond 25 years in case of off-peak period discharge.

For the 34 kWh battery storage system, the energy loss during the weekend is around 1,175 kWh/day or 2,350 kWh/week due to the factory not being able to sell the excess energy.

<u>Factory 2:</u>

In the case where the factory installs a 143-kWh battery storage system to store 100% of electricity generated during the weekdays, the result shows that the IRR is 12.8% and the payback period is 5 years when discharging in peak periods. The IRR is reduced to 4.8% and the payback period is extended to 7 years in case of off-peak period discharge.

In the case of installing a 268 kWh battery storage system to store electricity generation during the weekend, the IRR is reduced to 2.5% and the payback period extended to 8 years when batteries discharge in peak periods. When the batteries discharge on off-peak time, the IRR is decreased to -2.8% and the payback period extended to 11 years.

For the case of 143 kWh battery storage system the energy loss is around 100 kWh/day or 200 kWh/week as the factory cannot not sell the excess energy.

Case 2: Factories can sell solar PV excess generation to the network system.

Factory 1:

Installation of a 34 kWh battery storage system allows 100% storage of excess solar PV generation during weekdays. However, there is still an excess of about 2,350 kWh/week, generated during weekends, which cannot be stored.

If this excess generation is sold to PEA, the IRR will be 78.4% and payback period will be one year, for peak period discharge. The IRR will however decrease a bit to 72.8% and when battery discharge on off-peak period. This case illustrates an example of high return because, there is not only savings because of self-consumption but also, additional revenues can be made from selling the surplus energy.

Factory 2:

Installation of a 143 kWh battery storage system will allow storage of 100% excess solar PV generation during weekdays but a 200 kWh/week surplus energy during weekends. This case shows a 15.5% IRR and payback period of 4 years when batteries discharge on peak times. For off-peak period discharge, IRR is reduced to 7.9% and payback period extended to 6 years.

5. Discussion

The daytime average electricity use during weekdays and weekends were different for factories 1 and 2. Factory 1 had clearly higher amount of electricity consumption during weekdays than weekends. Factory 2 had almost the same level of electricity use between weekdays and weekends. The installation of a large solar PV systems for self-consumption can lead to excess energy production, which increases energy losses and, lead also to negative impacts on the distribution system [4,5].

This research investigated and compared the effects of the installation of battery storage to reduce energy losses in both factories which have installed large solar PV systems. The study showed that the installation of battery storage system can increase the economic feasibility of the PV systems, because additional revenues can be generated for the factories from selling excess electricity generation [11]. This is explained further below.

The 34 kWh battery storage system can be fully charge and discharge within a day during weekdays, but there are high losses from the excess solar PV generation on weekends. The 1,503 kWh battery storage system can also fully charge and discharge within a day, but its efficiency is quite low. This difference in battery size can affect the economic feasibility of the batteries. The study shows an appropriate economic analysis for the 34 kWh battery storage system to store energy and discharge during peak periods for factory 1, but energy losses is still a lot.

In case of factory 2, the 143 kWh and 268 kWh battery installations have little difference between them. The 143 kWh battery storage system can support daily charge/discharge operation, but there is still little energy losses in weekend. On the other hand, the 268 kWh battery installation can eliminate the entire energy losses. In both cases, the installation of batteries to store and discharge energy during peak period provides the most economic benefits.

If both factories can sell the surplus solar PV generation, even small battery sizes will be sufficient for economic investment due to increased revenue from selling electricity. In case of large battery sizes, there will be no change in economic benefits because no excess solar PV generation will be available for sale.

6. Conclusions

This study analyzed and compared solar PV installations for self-consumption for two factories, which had different average load characteristics. The selection of appropriate battery storage size for energy losses reduction was carried out. The economic feasibility in terms of IRR and payback period of each case were evaluated. The study showed that for these solar PV systems, the selection of the battery size selection to decrease energy losses should consider the load characteristic, as well as the economic feasibility analysis. The results showed that the installation of battery storage would reduce the reversed power flow, and the impacts on the power quality of the PEA network, and would even increase system stability and reliability.

The results of the research support and encourage battery storage installation to support solar PV generation. However, economic factors and other necessary assumptions should be taken into consideration to achieve consistent and beneficial results.

Acknowledgements

Authors would like to thank Provincial Electricity Authority and representatives of industrial factory for precious time, informative data, advises and recommendation of this study.

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