Analysis of Integrated Battery Energy Storage System with 1 MW Solar Power Plant

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Abstract
The research aims to evaluate the efficiency of Battery Energy Storage System (BESS) and provide recommendations for its improvement. Efficiency calculations involve comparing the input and output energy of BESS, utilizing data retrieved from the Rapid SCADA system in the Control Room (CR) of Solar Power Plant The main findings of this study indicate an overall BESS efficiency of 62.95% and a specific efficiency of 50% for the year 2023. The observed lower efficiency is attributed to a charging system employing excessively high voltages. This overvoltage charging also contributes to an estimated 17% increase in BESS battery degradation.

***Keywords*:** *BESS, Efficiency, Solar Power Plant*.

Abstrak
Penelitian ini bertujuan untuk mengevaluasi efisiensi BESS dan memberikan rekomendasi perbaikannya. Perhitungan efisiensi melibatkan perbandingan energi input dan output BESS, menggunakan data yang diambil dari sistem Rapid SCADA di Control Room (CR) Pembangkit Listrik Tenaga Surya. Temuan utama penelitian ini menunjukkan efisiensi BESS secara keseluruhan sebesar 62,95% dan efisiensi spesifik sebesar 50% untuk tahun 2023. Efisiensi yang lebih rendah ini disebabkan oleh sistem pengisian yang menggunakan tegangan terlalu tinggi. Pengisian daya tegangan berlebih ini juga berkontribusi terhadap peningkatan degradasi baterai BESS sebesar 17%.

***Keywords*:** *BESS, Efisiensi, Pembangkit Listrik Tenaga Surya*.

1. Introduction

Currently, the development of EBT refers to Presidential Decree Number of 5 of 2006 concerning National Energy Policy. Efforts to develop bioenergy, fuel cells, wind energy, and solar energy continue to be made (R. Amalia et al, 2023; Amalia, R et al, 2020; R. Amalia et al, 2020; R. Amalia et al, 2018). Solar Power Plants are a type of new, renewable energy that utilizes solar energy as the main source. PLTS is an energy generation system created with the main aim of researching Solar Power Plants systems in Indonesia with a capacity of 1 MW that uses solar panels with thin film technology. Solar panels with this technology were chosen because they are relatively cheap compared to other technologies (J. W. Stevens and G. P. Corey, 1996) and have higher efficiency under low irradiation conditions (K. Li and K. J. Tseng, 2015).

Solar Power Plants uses solar panels in the form of the Solar Frontier SF-170S and uses 2 types of inverters, namely central nd string inverters. The purpose of using these two types of inverters is research that can be used as a reference for the next Solar Power Plants development.

Solar Power Plants is also equipped with a Battery Energy Storage System or BESS (Hill, C. A. et al 2012; Datta, U et al, 2021; Pathak, P. K. et al, 2018; Olabi, A. G et al, 2022;). This system aims to store energy when Solar Power Plants produces more energy than it uses and can release energy when energy demand is more than energy production. This BESS uses a bi-directional inverter and VRLA lead acid battery to store this energy. The existence of the BESS system makes Solar Power Plants capable of working on an off-grid system but under normal conditions ,it works on an on-grid system (Rana, M. M et al, 2022; Liu, J et al, 2020; Banguero, E et al, 2020; Journal, Editorial T, 2017; Tejero-Gómez et al, 2023).

Batteries in Solar Power Plants play a major role as an energy storage system that supports overall performance. In designing a Battery Energy Storage System (BESS) for Solar Power Plants, understanding the system characteristics is crucial. Aspects that need to be considered involve an in-depth understanding of how energy is stored during the battery charging process. Understanding this process in detail can help increase the overall efficiency of the solar PV system. One of the positive impacts that can be generated is an increase in the Performance Ratio (PR), which is a key parameter in measuring Solar Power Plants efficiency performance.

BESS is a system that functions to store excess energy produced by solar panels for use when there is a shortage of energy from solar panels. This system has 2 main components, namely:

- Bi-directional inverter
  A bi-directional inverter is a device that can change AC to DC and can also change DC o AC. In BESS, this tool is responsible for converting AC rom the inverter into DC to charge the battery and converting DC from the battery into AC when needed. This tool is connected to the A bus system of the Solar Power Plants and can provide up to 100kW of power when needed.
- Battery
  The battery used in the 1MW Solar Power Plants is a VRLA-type lead acid battery. This battery is a Narada REXC-800 deep cycle battery which has a nominal voltage of 2V and a capacity of 800Ah. There are 352 batteries designed in series in this BESS system with a total voltage of 704V.

In general, the Battery Energy Storage System (BESS) in Solar Power Plants is run at a high State of Charge (SOC) level or almost reaches full capacity. This operational strategy is designed to achieve an optimal level of readiness, where the BESS is expected to be able to meet electricity needs even when weather conditions are less favorable and solar cells cannot produce electricity according to market demand. The application of this high SOC is expected to increase the BESS's ability to provide power during bad weather, providing resilience and reliability in providing electricity, especially in the most unfavorable weather conditions.

However, the use of high SOC can reduce battery efficiency (J. W. Stevens and G. P. Corey, 1996). Generally, battery charging efficiency tends to be high, creating optimal performance during the charging process. This charging efficiency is highest at the start of charging but will decrease as it approaches full condition. This condition often occurs when BESS based on lead acid batteries is in float condition. This condition does not occur in lithium-based BESS (K. Li and K. J. Tseng, 2015).

Float voltage is the voltage maintained by the battery when it is fully charged but not in use. In other words, it is the voltage level that keeps the battery in a fully charged state without exceeding it. If the float voltage is too high, it can increase battery temperature and reduce BESS efficiency or even damage the battery (Huang, H. and Nguyen, T. V, 1997).

This research aims to determine the efficiency of the BESS system in Solar Power Plants and how to increase the efficiency of the BESS system.

2. Methodology

This research method is described in flowchart form as follows.

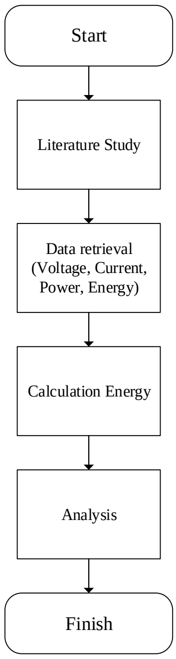

Figure 1. Research Flowchart

The efficiency of a battery can be calculated by dividing the amount of energy that comes out of the battery by the amount of energy that goes into the battery and then multiplying by 100%:

$$\eta=\frac{E(out)}{E(in)}x100\% \quad (1)$$

This value can be taken via the Rapid SCADA system from the Control Room (CR) at the Solar Power Plants. The data taken is total energy data that has entered and left the battery, as well as daily data that can be processed again. The data resulting from the Rapid SCADA system is .xml type data which can then be processed with the Excel application to get the desired power.

3. Result and Discussion

The efficiency of a battery can be calculated by dividing the amount of energy that comes out of the battery by the amount of energy that goes into the battery and then multiplying by 100%:

$$\eta = \frac{E(out)}{E(in)} x100\% \quad (1)$$

The energy entering and leaving the battery can be taken from the total charge and total discharge of the Rapid SCADA system on a 1 MW Solar Power Plants, so that we get:

$$\eta = \frac{90862.50kWh}{144344.1kWh} x100\%$$

$$\eta = 62.95\%$$

On January 1 - November 29 2023 the BESS system on the 1MW Solar Power Plants has efficiency:

$$\eta = \frac{4232.4kWh}{8449.3kWh} x100\%$$

$$\eta = 50.09\%$$

From these calculations, the overall system efficiency is 62.95% with a specific efficiency of 50% in 2023. This efficiency value is a less than optimal value when compared to the efficiency value of the lithium-based BESS (K. Li and K. J. Tseng, 2015).

The main cause of this less than optimal efficiency lies in the battery charging system used by the BESS. The charging mechanism regulated by the two-way inverter in Solar Power Plants is carried out less than optimally, which has the potential to cause a decrease in overall system performance. One of the key factors contributing to this less than optimal performance is the use of higher voltage targets.

In the recommended charging for Narada lead acid batteries, a float condition charge of 2.25V per cell is recommended. With the integration of 351 batteries into the system, a float charging voltage of 790V is required. This emphasizes the critical role that the charging and protection system plays in the overall efficiency of the BESS.

However, in reality this bi-directional inverter charges the battery with a voltage of more than 810V. This results in overcharging the battery which results in overvoltage on the battery. In this situation, the excess voltage is converted by the battery into heat energy, which ultimately increases the overall temperature of the battery (Huang, H. and Nguyen, T. V, 1997).

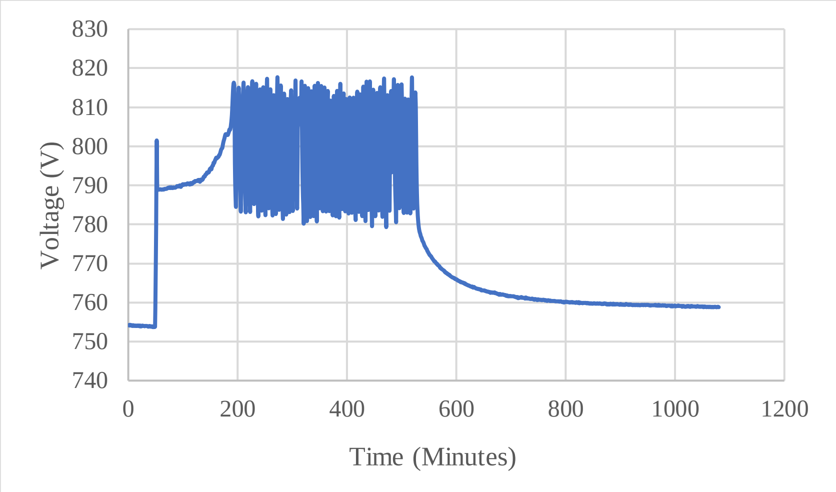

Figure 2. Influence of Time on Float Charging Voltage 29 November 2023

Overcharging results in inefficient energy use. The excess heat generated during overcharging is wasted energy that could be utilized. The energy wasted by battery dissipation can reduce the Performance Ratio (PR) of the Solar Power Plants system. In November 2023 the BESS at Solar Power Plants uses 433.7 kWh of energy.

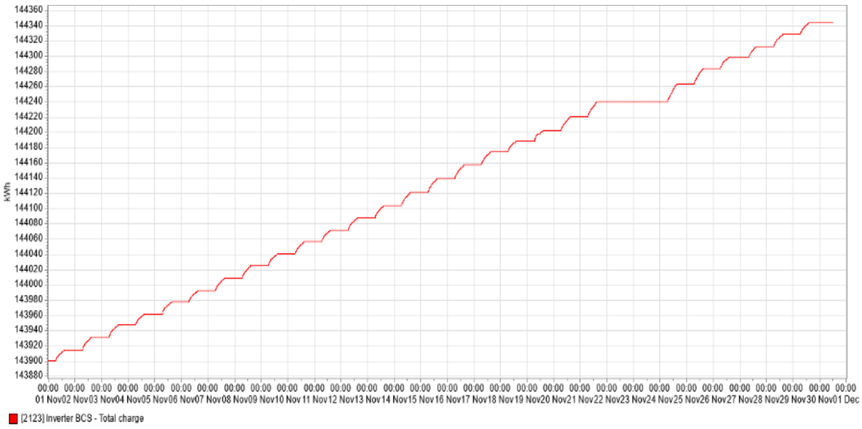

Figure 3. Correlation of time on Battery Energy Solar Power Plant

Not only does it reduce energy, charging at such high voltages also poses a potential risk of threatening the long-term integrity and degradation of battery cells. Although battery cells naturally undergo a degradation process during use, operation beyond standard operational limits can significantly accelerate this natural wear process, resulting in a shorter lifespan and reduced performance over time.

To assess the current condition of the battery, you can calculate the amount of energy coming out of the battery cell. This important data can be taken from the logs produced by the bi-directional inverter during the use of off-grid mode in Solar Power Plants on 23-28 June 2023. Analysis of this data can provide battery performance under certain operational conditions.

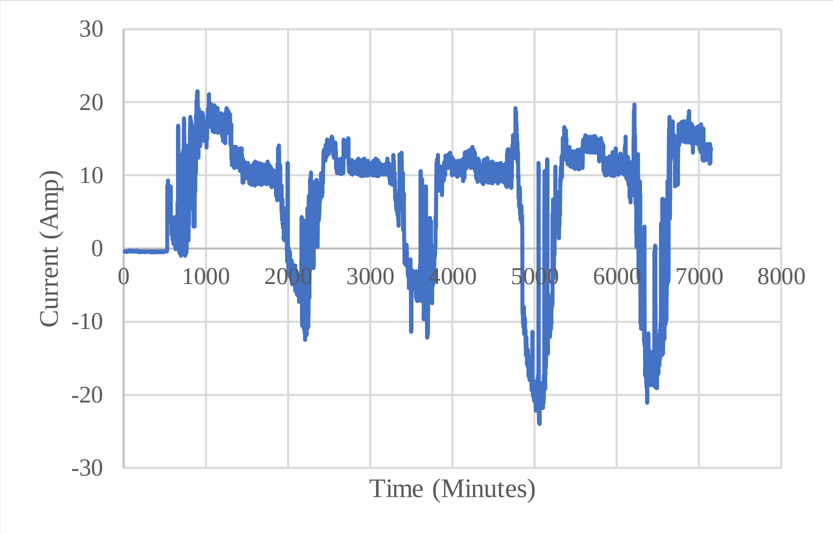

Figure 4. Influence of Time on Current Bi-Directional Inverter

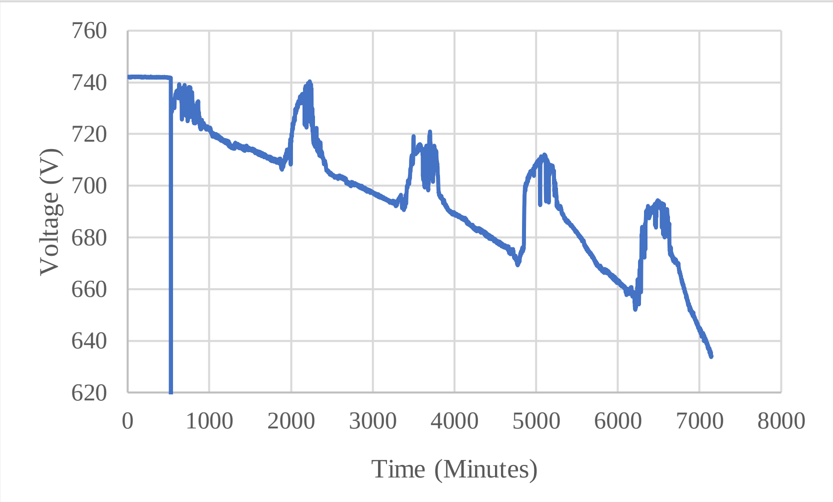

Figure 5. Influence of Time on Battery Voltage

From this data, it can be observed that there is a charge and discharge cycle in the battery. It can be observed that the battery is discharged at 999.8 Ah and charged at 202.8 Ah. From this data, it can be estimated that the battery capacity on June 28 2023 will be 797 Ah. This capacity has decreased from the factory capacity of 960Ah or a decrease of 17% from the initial capacity.

4. Conclusion

From the research above, conclusions can be drawn, including:

1. From the calculations that have been carried out, the BESS system in Solar Power Plants has an overall efficiency of 62.95% and a specific efficiency of 50% in 2023.
2. Increasing efficiency in the **Solar Power Plants** BESS system can be achieved by lowering the charging voltage target to reduce overcharging of the battery which can cause excessive energy expenditure. By adjusting the charging voltage target, overcharging conditions can

be avoided which results in wasted energy in the form of heat. This solution can optimize the use of stored energy, and extend battery life in the long term

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