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RESEARCH ARTICLE

# Optimal Battery Energy Storage System Placement Strategy in Central Java Electrical System for Voltage and Losses Improvement

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**Abstract**

Over the past few decades, advances in energy storage technology, particularly in the form of Battery Energy Storage Systems (BESS), have provided innovative solutions to address various challenges in the power grid such as voltage fluctuations and high levels of losses, which negatively impact the efficiency and quality of electricity provision. BESS has advantages over other energy storage technologies such as having lower costs, faster response times to power equipment or devices, and increased efficiency and flexibility. The purpose of this research is to determine the optimal capacity and location of the placement of BESS to get an improvement in the voltage profile and losses in the Central Java Province power system. In this study, BESS is incorporated into the Jelok substation based on the calculation method under day and night conditions, which will be sought for the most optimal placement. After getting the most optimal placement, the optimal BESS capacity based on the calculation method, 15 MWh, and 25 MWh will be compared. The effect of optimum BESS placement and sizing improves the voltage values of up to 1.3% and reduces power losses of up to 1.87 MW.

**Keywords:** Battery Energy Storage System, location, losses, sizing, voltage profile

## 1. Introduction

Technology is developing rapidly in the world due to increasing needs. Energy is the main requirement used for survival [1]. One of the energies needed is electrical energy. The use of electrical energy in Indonesia continues to increase. On the other hand, Indonesia is facing an increasing scarcity of fossil fuels. The contribution of new and renewable energy is targeted to go up by 23% of Indonesia's energy consumption, according to the government's energy mix program [2].

All devices today consume significant amounts of electrical energy due to technological advances [3]. With the population continuing to increase and technology becoming more advanced, the demand for electrical energy is increasing. In this case, it is very important to maintain the quality of electricity. When loads are considered dynamic in nature, stability becomes an important metric for evaluating the quality of an electric power system. It is very important to keep the voltage and frequency of active power and reactive power in balance during the energy supply process.

Research on improving electricity quality has produced several innovative findings [4]. One of the factors that contributes to the rapid expansion of renewable energy use in Indonesia today is the availability of storage systems that can distribute power in a timely manner [5]. Battery Energy Storage Systems (BESS) have been widely used in providing grid services such as voltage support, energy arbitrage, frequency management, and more. For BESS, experts have created state-of-the-art algorithms for control and optimization. To meet operating requirements while maintaining battery life, advanced optimization and control techniques are used [6].

To respond to electricity needs, BESS is a technology that can operate in a quick manner [7]. BESS is an energy storage system that stores and distributes electricity using batteries [8]. Power grids and similar applications make extensive use of this technology. This is because electricity can be stored by the BESS for later use. Various power demands can be met by utilizing stored energy [9].

Compared to other energy storage systems, BESS offers several benefits, including lower costs, faster response times to power on equipment or devices, and increased efficiency and flexibility. The significance of BESS in power systems is increasing because of the imbalance between electricity supply and demand [6]. With BESS, the frequency performance of the power system is further improved because it can improve the voltage profile while reducing losses [10].

Electricity use in Central Java Province, as with the other provinces in Indonesia, continues to increase every year. The results of a study of data obtained from the Central Statistics Agency found that the energy distributed in this province was 24,558.02 GWh in 2018, 24,750.62 GWh in 2019, 25,090.74 GWh in 2020, 26,661.16 GWh in 2021, and 27,564.64 GWh in 2022 [2]. To mitigate the problem of increasing power demands and losses, this research seeks to carry out an optimal analysis of the BESS design.

Several studies have explored the potential use of BESS to improve voltage profile and reduce losses in a power system. The authors at [11] proposed a two-step optimization approach for BESS addition to a distribution network with renewable energy sources, to achieve lowest possible costs, and low voltage deviation from its nominal value. The authors at [12] has the same objective as [11], albeit by using three optimization algorithms, i.e. genetic algorithm, particle swarm optimization, and salp swarm algorithm. Meanwhile, the authors at [13] has another approach by incorporating the modified lightning search algorithm into the same objective.

The main objective and contribution of this research is to provide a thorough analysis of optimal BESS placement in a large power system, e.g. Central Java power system, and to provide a framework of comparison between different sizing methodologies. This research is structured as follows: Section 2 describes the methodology of this research. Section 3 includes simulation configuration, results, and comparison between different parameters under study. Finally, conclusions are given in Section 4.

## 2. Research Methodology

The flowchart of the methodology used in this research can be seen in Figure 1. The research was carried out on the electricity system in Region 3 of Jawa-Madura-Bali (JAMALI) system, which is primarily located in Central Java. A selection of the most optimal substation for this research is done by inserting BESS at several substations that have considerably high voltage drops and losses. The modification by BESS insertion is done in the Single Line Diagram (SLD) of the Region 3 system using DIgSILENT PowerFactory software, to simulate power flow in two scenarios: outside of peak load times at daytime and peak load times during the night. Furthermore, the calculation of BESS capacity and optimum placement inside the system are considered. Two BESS capacity scenarios are considered, i.e. 15 MWh and 25 MWh, to be varied at the BESS in its optimal placement. Simulation results, i.e. voltage level and the amount of power losses are then analyzed and compared between the configurations, according to the calculation and the battery capacity based on the scenario.

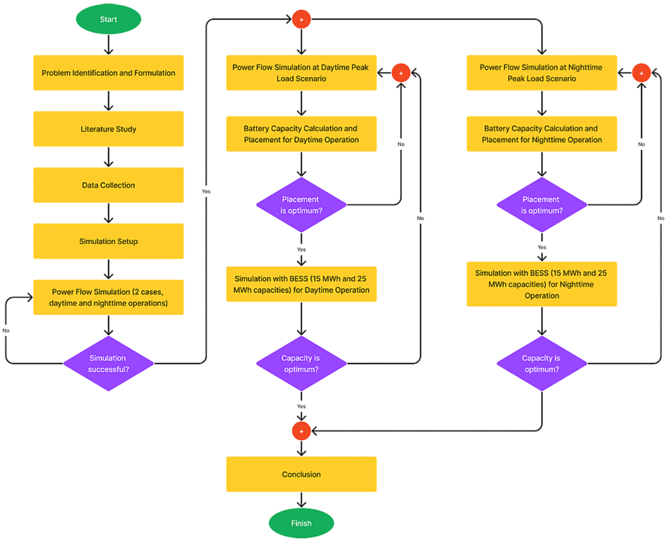


**Figure 1.** Flowchart of Research Methodology

## 3. Result and Discussion

### *3.1 Selection of the Optimum Substation for BESS Placement*

The selection of the optimum substation for BESS placement is done by carrying out power flow simulations in the existing Region 3 system. Out of all substations in the system, Kudus, Krapyak, and Jelok substations are considered to have noticeable amount of voltage drop and losses. A further selection is carried out by determining the optimum substation for BESS placement, i.e. between Kudus, Krapyak, and Jelok substations, with a target of the best voltage profile and low losses compared to the other substations. After several load flows, it is found that the Jelok substation is the most optimum substation for BESS placement. After obtaining the optimum placement, further case studies are needed to compare the effectiveness of the installed BESS capacity.

### *3.2 Optimum BESS Placement in Daytime Conditions*

During daytime conditions, the battery primarily charges from the power system, therefore functioning as a load. The optimum capacity of BESS is determined based on conditions such as battery type, Depth of Discharge (*DoD*), and total load at the system. Based on system analysis through simulation, it is found that the optimum BESS capacity for daytime operation is 19.92 MWh.

There are 3 substations which are connected to the Jelok substation, i.e. Bringin, Sanggrahan, and Ungaran. The data of voltage conditions for each substations prior to and after the addition of 19.92 MWh BESS are shown in Table 1, while the losses for each transmission lines which connects each substations are shown in Table 2.

**Table 1.** Voltage Conditions Before and After BESS Placement at Jelok Substation During the Day

| No | Substation | Voltage | | Change |
|---|---|---|---|---|
| | | Without BESS (pu) | With 19.92 MWh BESS (pu) | |
| 1 | BRINGIN | 0.9955 | 0.9937 | -0.18% |
| 2 | JELOK | 1.0059 | 1.0040 | -0.19% |
| 3 | SANGGRAHAN | 1.0057 | 1.0052 | -0.05% |
| 4 | UNGARAN | 1.0316 | 1.0310 | -0.06% |

**Table 2.** Losses Before and After BESS Placement at Jelok Substation During the Day

| No | Transmission Line | Losses | | Change |
|---|---|---|---|---|
| | | Without BESS (MW) | With 19.92 MWh BESS (MW) | |
| 1 | BRINGIN-JELOK1 | 0.5251 | 0.5269 | 0.34% |
| 2 | BRINGIN-JELOK2 | 0.5251 | 0.5269 | 0.34% |
| 3 | SANGGRAHAN-JELOK1 | 0.1254 | 0.1258 | 0.32% |
| 4 | SANGGRAHAN-JELOK2 | 0.1254 | 0.1258 | 0.32% |
| 5 | UNGARAN-JELOK1 | 1.3131 | 1.1584 | -11.78% |
| 6 | UNGARAN-JELOK2 | 1.3131 | 1.1584 | -11.78% |
| **Total** | | **3.9272** | **3.6222** | **-7.77%** |

#### *3.2.1 Case 1: Placement of 15 MWh-BESS in Daytime Conditions*

Power flow analysis was carried out at peak load conditions during the day with a BESS capacity of 15 MWh at the Jelok Substation, to determine the condition of voltage and losses at Jelok substation and the entire Central Java Region 3 system, as

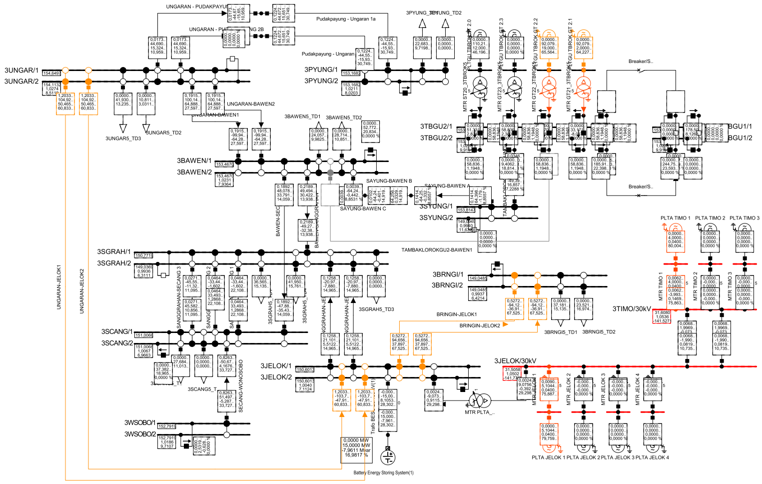


**Figure 2.** Load Flow after BESS Placement During Daytime Conditions (Case 1: BESS 15 MWh)

seen in Figure 2. The black colour indicates normal operating parameters, while the orange and red colours indicate a higher amount of loading in the system.

In the existing condition, the voltage at the Jelok Substation was 1.0059 pu, and after the 15 MWh-BESS placement, the voltage becomes 1.0040 pu. The result of voltage and losses before and after the BESS enters the Jelok substation can be seen in Table 3 and Table 4.

**Table 3.** Voltage Conditions Before and After BESS Placement at Jelok Substation During the Day

| No | Substation | Voltage | | Change |
|---|---|---|---|---|
| | | Without BESS (pu) | With 15 MWh BESS (pu) | |
| 1 | BRINGIN | 0.9955 | 0.9937 | -0.18% |
| 2 | JELOK | 1.0059 | 1.0040 | -0.19% |
| 3 | SANGGRAHAN | 1.0057 | 1.0052 | -0.05% |
| 4 | UNGARAN | 1.0316 | 1.0310 | -0.06% |

**Table 4.** Losses Before and After BESS Placement at Jelok Substation During the Day

| No | Transmission Line | Losses | | Change |
|---|---|---|---|---|
| | | Without BESS (MW) | With 15 MWh BESS (MW) | |
| 1 | BRINGIN-JELOK1 | 0.5251 | 0.5272 | 0.40% |
| 2 | BRINGIN-JELOK2 | 0.5251 | 0.5272 | 0.40% |
| 3 | SANGGRAHAN-JELOK1 | 0.1254 | 0.1258 | 0.32% |
| 4 | SANGGRAHAN-JELOK2 | 0.1254 | 0.1258 | 0.32% |
| 5 | UNGARAN-JELOK1 | 1.3131 | 1.2033 | -8.36% |
| 6 | UNGARAN-JELOK2 | 1.3131 | 1.2033 | -8.36% |
| **Total** | | **3.9272** | **3.7126** | **-5.46%** |

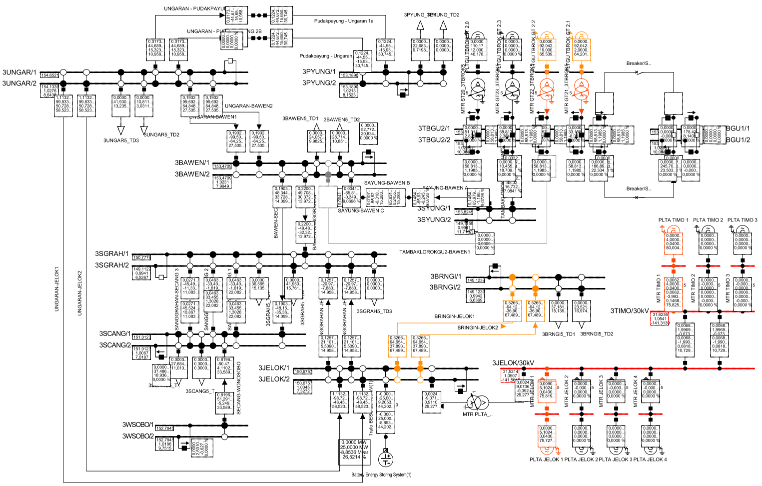


**Figure 3.** Load Flow after BESS Placement During Day time Conditions (Case2: BESS 25 MWh)

It is found that the total losses of the entire transmission lines which are connected to Jelok substation has reduced from 3.9272 MW to 3.7126 MW. However, the condition of losses on each network has not changed significantly. The Bringin-Jelok line experienced an increase in losses from 0.5251 MW to 0.5272 MW. The Sanggrahan-Jelok line experienced an increase from 0.1254 MW to 0.1258 MW. The Ungaran-Jelok line decreased from 1.3131 MW to 1.2033 MW. This is due to the type of conductor and length of transmission line of each transmission network. By installing the BESS in the Jelok substation which supplies active power, it causes an increase in the value of losses on the line. Thus, there is a need for further case studies to compare the effectiveness of the installed BESS capacity.

### *3.2.2 Case 2: Placement of 25 MWh-BESS in Daytime Conditions*

Another power flow analysis was carried out at peak load conditions during the day with a BESS capacity of 25 MWh at the Jelok Substation, to determine the condition of voltage and losses at Jelok substation and the entire Central Java Region 3 system, as seen in Figure 3. The black colour indicates normal operating parameters, while the orange and red colours indicate a higher amount of loading in the system.

In the existing condition, the voltage at the Jelok Substation was 1.0059 pu, and after the 25 MWh-BESS placement, the voltage becomes 1.0040 pu. The result of voltage and losses before and after the BESS enters the Jelok substation can be seen in Table 5 and Table 6.

**Table 5.** Voltage Conditions Before and After BESS Placement at Jelok Substation During the Day

| No | Substation | Voltage | | Change |
|---|---|---|---|---|
| | | Without BESS (pu) | With 25 MWh BESS (pu) | |
| 1 | BRINGIN | 0.9955 | 0.9942 | -0.13% |
| 2 | JELOK | 1.0059 | 1.0045 | -0.14% |
| 3 | SANGGRAHAN | 1.0057 | 1.0052 | -0.05% |
| 4 | UNGARAN | 1.0316 | 1.0310 | -0.06% |

**Table 6.** Losses Before and After BESS Placement at Jelok Substation During the Day

| No | Transmission Line | Losses | | Change |
|---|---|---|---|---|
| | | Without BESS (MW) | With 25 MWh BESS (MW) | |
| 1 | BRINGIN-JELOK1 | 0.5251 | 0.5266 | 0.29% |
| 2 | BRINGIN-JELOK2 | 0.5251 | 0.5266 | 0.29% |
| 3 | SANGGRAHAN-JELOK1 | 0.1254 | 0.1257 | 0.24% |
| 4 | SANGGRAHAN-JELOK2 | 0.1254 | 0.1257 | 0.24% |
| 5 | UNGARAN-JELOK1 | 1.3131 | 1.1132 | -15.22% |
| 6 | UNGARAN-JELOK2 | 1.3131 | 1.1132 | -15.22% |
| **Total** | | **3.9272** | **3.5310** | **-10.09%** |

It is found that the total losses of the entire transmission lines which are connected to Jelok substation has reduced from 3.9272 MW to 3.5310 MW. However, the condition of losses on each network has also not changed significantly. The Bringin-Jelok line experienced an increase in losses from 0.5251 MW to 0.5266 MW. The Sanggrahan-Jelok line experienced an increase from 0.1254 MW to 0.1257 MW. The Ungaran-Jelok line decreased from 1.3131 MW to 1.1132 MW. This is due to the type of conductor and length of transmission line of each transmission network. By installing the BESS in the Jelok substation which supplies active power, it causes an increase in the value of losses on the line.

### *3.2.3 Comparison Between Case 1 and Case 2 During Daytime Conditions*

The comparison between the results of Case 1 (15 MWh BESS) and Case 2 (25 MWh BESS) during daytime conditions can be seen in Table 7 and Table 8. There are differences in the voltage profile around the Jelok substation in several cases. The best voltage profile improvement is obtained using Case 2. Meanwhile, the best reduction in losses occurred with the BESS capacity of 25 MWh. This can also be influenced by several factors, including the type of conductor resistance and the cross-sectional area of the conductor.

**Table 7.** Voltage Conditions Before and After BESS Placement at Jelok Substation During the Day

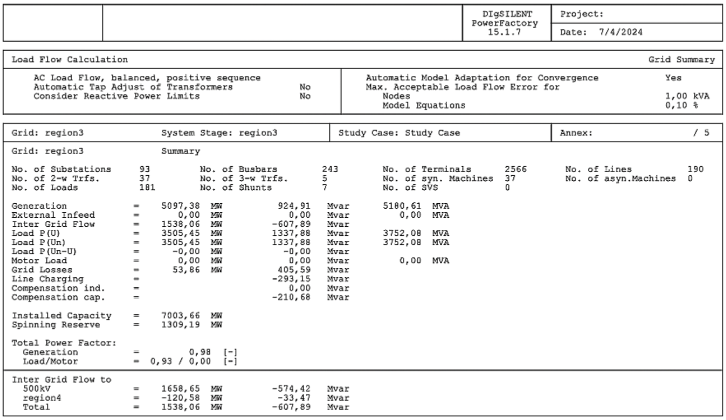
| No | Substation | Voltage | | | |
|---|---|---|---|---|---|
| | | Without BESS (pu) | With 19.92 MWh BESS (pu) | Case 1 – With 15 MWh BESS (pu) | Case 2 – With 25 MWh BESS (pu) |
| 1 | BRINGIN | 0.9955 | 0.9942 | 0.9937 | 0.9942 |
| 2 | JELOK | 1.0059 | 1.0045 | 1.0040 | 1.0045 |
| 3 | SANGGRAHAN | 1.0057 | 1.0052 | 1.0051 | 1.0052 |
| 4 | UNGARAN | 1.0316 | 1.0310 | 1.0310 | 1.0310 |

**Table 8.** Losses Before and After BESS Placement at Jelok Substation During the Day

| No | Transmission Line | Losses | | | |
|---|---|---|---|---|---|
| | | Without BESS (MW) | With 19.92 MWh BESS (MW) | Case 1 – With 15 MWh BESS (MW) | Case 2 – With 25 MWh BESS (MW) |
| 1 | BRINGIN-JELOK1 | 0.5251 | 0.5269 | 0.5272 | 0.5266 |
| 2 | BRINGIN-JELOK2 | 0.5251 | 0.5269 | 0.5272 | 0.5266 |
| 3 | SANGGRAHAN-JELOK1 | 0.1254 | 0.1258 | 0.1258 | 0.1257 |
| 4 | SANGGRAHAN-JELOK2 | 0.1254 | 0.1258 | 0.1258 | 0.1257 |
| 5 | UNGARAN-JELOK1 | 1.3131 | 1.1584 | 1.2033 | 1.1132 |
| 6 | UNGARAN-JELOK2 | 1.3131 | 1.1584 | 1.2033 | 1.1132 |
| **Total** | | **3.9272** | **3.6222** | **3.7126** | **3.5310** |

### *3.2.4 Voltage and Losses Improvement in Central Java During Daytime Conditions*

Prior to the placement of BESS, the average voltage in Central Java Province was 1.0206 pu, and after the placement of BESS the voltage became 1.0191 pu. There is an improvement in the voltage profile of 0.0015 pu after the placement of BESS at Jelok substation. Meanwhile, it is found that the losses before the placement of BESS in Central Java Province were 53.86 MW, as seen in Figure 4, and after the placement of BESS the losses were 53.15 MW, as seen in Figure 5. Therefore, there is a reduction in losses of 0.71 MW after the placement of BESS at Jelok substation during daytime conditions.



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                                                                DIgSILENT    Project:
                                                              PowerFactory
                                                                 15.1.7      Date:  7/4/2024

Load Flow Calculation                                                                        Grid Summary
    AC Load Flow, balanced, positive sequence               Automatic Model Adaptation for Convergence        Yes
    Automatic Tap Adjust of Transformers          No        Max. Acceptable Load Flow Error for
    Consider Reactive Power Limits                No           Nodes                                          1,00 kVA
                                                               Model Equations                                0,10 %

Grid: region3              System Stage: region3        Study Case: Study Case              Annex:            / 5
Grid: region3              Summary

No. of Substations     93        No. of Busbars        243       No. of Terminals     2566       No. of Lines          190
No. of 2-w Trfs.       37        No. of 3-w Trfs.      5         No. of syn. Machines 37         No. of asyn.Machines  0
No. of Loads           181       No. of Shunts         7         No. of SVS           0

Generation           =    5097,38  MW          924,91   Mvar    5180,61  MVA
External Infeed      =       0,00  MW            0,00   Mvar       0,00  MVA
Inter Grid Flow      =    1538,06  MW         -607,89   Mvar
Load P(U)            =    3505,45  MW         1337,88   Mvar    3752,08  MVA
Load P(Un)           =    3505,45  MW         1337,88   Mvar    3752,08  MVA
Load P(Un-U)         =      -0,00  MW           -0,00   Mvar
Motor Load           =       0,00  MW            0,00   Mvar       0,00  MVA
Grid Losses          =      53,86  MW          405,59   Mvar
Line Charging        =                        -293,15   Mvar
Compensation ind.    =                           0,00   Mvar
Compensation cap.    =                        -210,68   Mvar

Installed Capacity   =    7003,66  MW
Spinning Reserve     =    1309,19  MW

Total Power Factor:
  Generation         =          0,98  [-]
  Load/Motor         =  0,93 / 0,00  [-]

Inter Grid Flow to
  500kV              =    1658,65  MW         -574,42   Mvar
  region4            =    -120,58  MW          -33,47   Mvar
  Total              =    1538,06  MW         -607,89   Mvar
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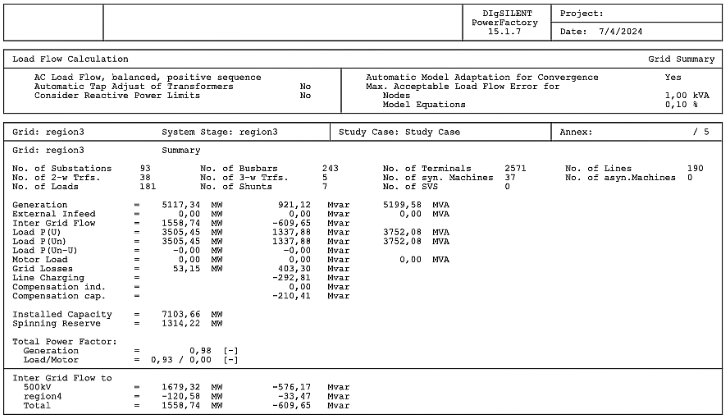
**Figure 4.** Losses Before BESS Placement in Central Java Province under Daytime Condition



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                                                                DIgSILENT    Project:
                                                              PowerFactory
                                                                 15.1.7      Date:  7/4/2024

Load Flow Calculation                                                                        Grid Summary
    AC Load Flow, balanced, positive sequence               Automatic Model Adaptation for Convergence        Yes
    Automatic Tap Adjust of Transformers          No        Max. Acceptable Load Flow Error for
    Consider Reactive Power Limits                No           Nodes                                          1,00 kVA
                                                               Model Equations                                0,10 %

Grid: region3              System Stage: region3        Study Case: Study Case              Annex:            / 5
Grid: region3              Summary

No. of Substations     93        No. of Busbars        243       No. of Terminals     2571       No. of Lines          190
No. of 2-w Trfs.       38        No. of 3-w Trfs.      5         No. of syn. Machines 37         No. of asyn.Machines  0
No. of Loads           181       No. of Shunts         7         No. of SVS           0

Generation           =    5117,34  MW          921,12   Mvar    5199,58  MVA
External Infeed      =       0,00  MW            0,00   Mvar       0,00  MVA
Inter Grid Flow      =    1558,74  MW         -609,65   Mvar
Load P(U)            =    3505,45  MW         1337,88   Mvar    3752,08  MVA
Load P(Un)           =    3505,45  MW         1337,88   Mvar    3752,08  MVA
Load P(Un-U)         =      -0,00  MW           -0,00   Mvar
Motor Load           =       0,00  MW            0,00   Mvar       0,00  MVA
Grid Losses          =      53,15  MW          403,30   Mvar
Line Charging        =                        -292,81   Mvar
Compensation ind.    =                           0,00   Mvar
Compensation cap.    =                        -210,41   Mvar

Installed Capacity   =    7103,66  MW
Spinning Reserve     =    1314,22  MW

Total Power Factor:
  Generation         =          0,98  [-]
  Load/Motor         =  0,93 / 0,00  [-]

Inter Grid Flow to
  500kV              =    1679,32  MW         -576,17   Mvar
  region4            =    -120,58  MW          -33,47   Mvar
  Total              =    1558,74  MW         -609,65   Mvar
```

**Figure 5.** Losses After BESS Placement in Central Java Province under Daytime Condition

## *3.3 Optimum BESS Placement at Night*

At night, the battery primarily discharges to the power system, therefore functioning as an energy supply. Based on system analysis through simulation, it is found that the optimum BESS capacity for daytime operation is 29.84 MWh. The data of voltage conditions for each substations prior to and after the addition of 29.84 MWh BESS are shown in Table 9, while the losses for each transmission lines which connects each substations are shown in Table 10.

**Table 9.** Voltage Conditions Before and After BESS Placement at Jelok Substation at Night

| No | Substation | Voltage | | Change |
|---|---|---|---|---|
| | | Without BESS (pu) | With 29.84 MWh BESS (pu) | |
| 1 | BRINGIN | 0.9696 | 0.9826 | 1.34% |
| 2 | JELOK | 0.9814 | 0.9942 | 1.30% |
| 3 | SANGGRAHAN | 0.9810 | 0.9841 | 0.32% |
| 4 | UNGARAN | 1.0117 | 1.0149 | 0.32% |

**Table 10.** Losses Before and After BESS Placement at Jelok Substation at Night

| No | Transmission Line | Losses | | Change |
|---|---|---|---|---|
| | | Without BESS (MW) | With 29.84 MWh BESS (MW) | |
| 1 | BRINGIN-JELOK1 | 0.6697 | 0.6510 | -2.79% |
| 2 | BRINGIN-JELOK2 | 0.6697 | 0.6510 | -2.79% |
| 3 | SANGGRAHAN-JELOK1 | 0.1460 | 0.1421 | -2.67% |
| 4 | SANGGRAHAN-JELOK2 | 0.1460 | 0.1421 | -2.67% |
| 5 | UNGARAN-JELOK1 | 1.6599 | 1.1995 | -27.74% |
| 6 | UNGARAN-JELOK2 | 1.6599 | 1.1995 | -27.74% |
| **Total** | | **4.9512** | **3.9852** | **-19.51%** |

### *3.3.1 Case 1: Placement of 15 MWh-BESS at Night*

Power flow analysis was carried out at peak load conditions during the night with a BESS capacity of 15 MWh at the Jelok Substation, to determine the condition of voltage and losses at Jelok substation and the entire Central Java Region 3 system, as seen in Figure 6. The black colour indicates normal operating parameters, while the orange and red colours indicate a higher amount of loading in the system.

In the existing condition, the voltage at the Jelok Substation was 0.9814 pu, and after the 15 MWh–BESS placement, the voltage becomes 0.9937 pu. The result of voltage and losses before and after the BESS enters the Jelok substation can be seen in Table 11 and Table 12.

**Table 11.** Voltage Conditions Before and After BESS Placement at Jelok Substation at Night

| No | Substation | Voltage | | Change |
|---|---|---|---|---|
| | | Without BESS (pu) | With 15 MWh BESS (pu) | |
| 1 | BRINGIN | 0.9696 | 0.9820 | 1.28% |
| 2 | JELOK | 0.9814 | 0.9937 | 1.25% |
| 3 | SANGGRAHAN | 0.9810 | 0.984 | 0.31% |
| 4 | UNGARAN | 1.0117 | 1.0149 | 0.32% |

**Table 12.** Losses Before and After BESS Placement at Jelok Substation at Night

| No | Transmission Line | Losses | | Change |
|---|---|---|---|---|
| | | Without BESS (MW) | With 15 MWh BESS (MW) | |
| 1 | BRINGIN-JELOK1 | 0.6697 | 0.6518 | -2.67% |
| 2 | BRINGIN-JELOK2 | 0.6697 | 0.6518 | -2.67% |
| 3 | SANGGRAHAN-JELOK1 | 0.1460 | 0.1422 | -2.60% |
| 4 | SANGGRAHAN-JELOK2 | 0.1460 | 0.1422 | -2.60% |
| 5 | UNGARAN-JELOK1 | 1.6599 | 1.3473 | -18.83% |
| 6 | UNGARAN-JELOK2 | 1.6599 | 1.3473 | -18.83% |
| **Total** | | **4.9512** | **4.2826** | **-13.50%** |

It is found that the total losses of the entire transmission lines which are connected to Jelok substation has reduced from 4.9512 MW to 4.2826 MW. The condition of

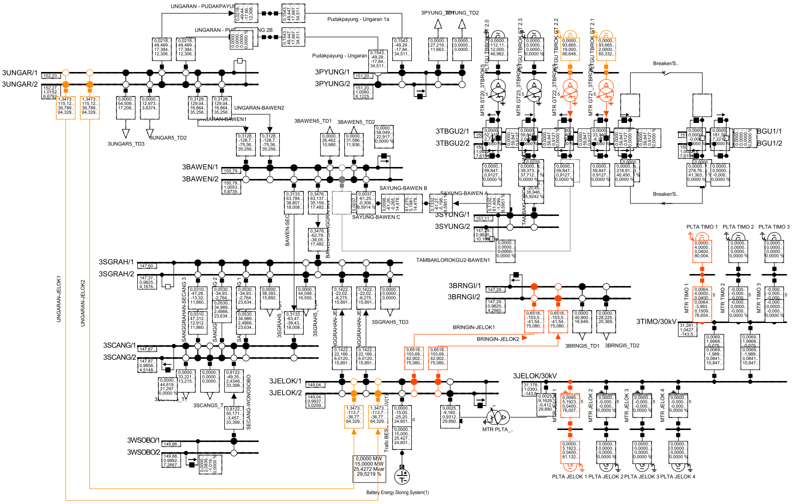


**Figure 6.** Load Flow after BESS Placement at Night (Case1: BESS 15 MWh)

losses on each network has also changed significantly. The Bringin-Jelok channel experienced a decrease in losses from 0.6697 MW to 0.6518 MW. The Sanggrahan-Jelok channel experienced a decrease from 0.1460 MW to 0.1422 MW. The Ungaran-Jelok channel decreased from 1.6599 MW to 1.3473 MW. Many lines are experiencing decrease in losses. This is because the type of conductor and channel length of each transmission network and the size of the installed battery capacity are large enough to reduce losses in the Jelok substation.

### 3.3.2 Case 2: Placement of 25 MWh-BESS at Night

Another power flow analysis was carried out at peak load conditions during the night with a BESS capacity of 25 MWh at the Jelok Substation, to determine the condition of voltage and losses at Jelok substation and the entire Central Java Region 3 system, as seen in Figure 7. The black colour indicates normal operating parameters, while the orange and red colours indicate a higher amount of loading in the system.

In the existing condition, the voltage at the Jelok Substation was 0.9814 pu, and after the 25 MWh-BESS placement, the voltage becomes 0.9940 pu. The result of voltage and losses before and after the BESS enters the Jelok substation can be seen in Table 13 and Table 14.

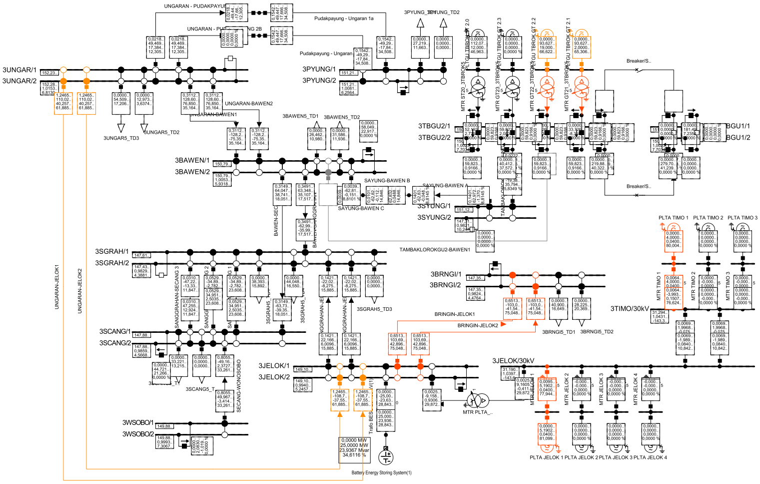


**Figure 7.** Load Flow after BESS Placement at Night (Case2: BESS 25 MWh)

**Table 13.** Voltage Conditions Before and After BESS Placement at Jelok Substation at Night

| No | Substation | Voltage | | Change |
|---|---|---|---|---|
| | | Without BESS (pu) | With 25 MWh BESS (pu) | |
| 1 | BRINGIN | 0.9696 | 0.9824 | 1.32% |
| 2 | JELOK | 0.9814 | 0.9940 | 1.28% |
| 3 | SANGGRAHAN | 0.9810 | 0.9841 | 0.32% |
| 4 | UNGARAN | 1.0117 | 1.0149 | 0.32% |

**Table 14.** Losses Before and After BESS Placement at Jelok Substation at Night

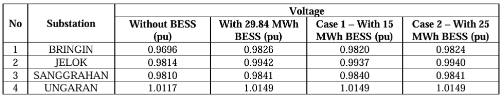
| No | Transmission Line | Losses | | Change |
|---|---|---|---|---|
| | | Without BESS (MW) | With 25 MWh BESS (MW) | |
| 1 | BRINGIN-JELOK1 | 0.6697 | 0.6513 | -2.75% |
| 2 | BRINGIN-JELOK2 | 0.6697 | 0.6513 | -2.75% |
| 3 | SANGGRAHAN-JELOK1 | 0.1460 | 0.1421 | -2.67% |
| 4 | SANGGRAHAN-JELOK2 | 0.1460 | 0.1421 | -2.67% |
| 5 | UNGARAN-JELOK1 | 1.6599 | 1.2465 | -24.91% |
| 6 | UNGARAN-JELOK2 | 1.6599 | 1.2465 | -24.91% |
| **Total** | | **4.9512** | **4.0798** | **-17.60%** |

It is found that the total losses of the entire transmission lines which are connected to Jelok substation has reduced from 4.9512 MW to 4.0798 MW. The Bringin-Jelok channel experienced a decrease in losses from 0.6697 MW to 0.6513 MW. The Sanggrahan-Jelok channel experienced a decrease from 0.1460 MW to 0.1421 MW. The Ungaran-Jelok channel decreased from 1.6599 MW to 1.2465 MW. Many lines are seen experiencing a decrease in losses. Many lines are experiencing decrease in losses. This is because the type of conductor and channel length of each transmission network and the size of the installed battery capacity are large enough to reduce losses in the Jelok substation.

### *3.3.3 Comparison Between Case 1 and Case 2 at Night*

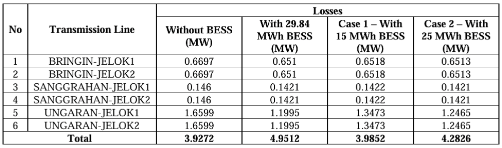
The comparison between the results of Case 1 (15 MWh BESS) and Case 2 (25 MWh BESS) during night conditions can be seen in Table 15 and Table 16. There are differences in the voltage profile around the Jelok substation in several cases. The best voltage profile improvement is obtained using the base case of 29.84 MWh. The same conclusion also applies with the losses occurred with the BESS capacity of 29.84 MWh, which is better (lower) than the other cases. This can also be influenced by several factors, including the type of conductor resistance and the cross-sectional area of the conductor.

**Table 15.** Voltage Conditions Before and After BESS Placement at Jelok Substation at Night



| No | Substation | Voltage | | | |
|---|---|---|---|---|---|
| | | **Without BESS (pu)** | **With 29.84 MWh BESS (pu)** | **Case 1 – With 15 MWh BESS (pu)** | **Case 2 – With 25 MWh BESS (pu)** |
| 1 | BRINGIN | 0.9696 | 0.9826 | 0.9820 | 0.9824 |
| 2 | JELOK | 0.9814 | 0.9942 | 0.9937 | 0.9940 |
| 3 | SANGGRAHAN | 0.9810 | 0.9841 | 0.9840 | 0.9841 |
| 4 | UNGARAN | 1.0117 | 1.0149 | 1.0149 | 1.0149 |

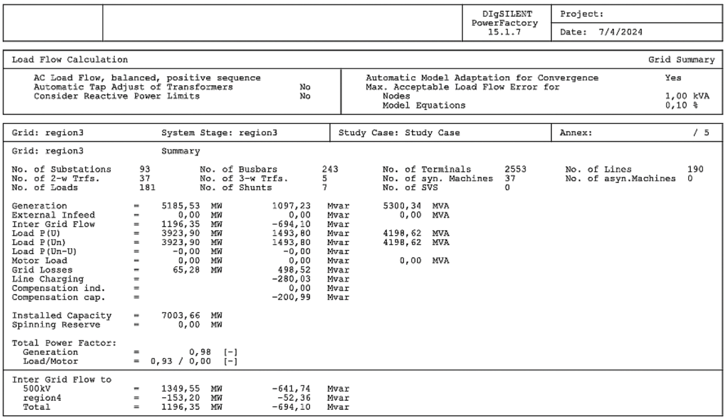
**Table 16.** Losses Before and After BESS Placement at Jelok Substation at Night



| No | Transmission Line | Losses | | | |
|---|---|---|---|---|---|
| | | **Without BESS (MW)** | **With 29.84 MWh BESS (MW)** | **Case 1 – With 15 MWh BESS (MW)** | **Case 2 – With 25 MWh BESS (MW)** |
| 1 | BRINGIN-JELOK1 | 0.6697 | 0.651 | 0.6518 | 0.6513 |
| 2 | BRINGIN-JELOK2 | 0.6697 | 0.651 | 0.6518 | 0.6513 |
| 3 | SANGGRAHAN-JELOK1 | 0.146 | 0.1421 | 0.1422 | 0.1421 |
| 4 | SANGGRAHAN-JELOK2 | 0.146 | 0.1421 | 0.1422 | 0.1421 |
| 5 | UNGARAN-JELOK1 | 1.6599 | 1.1995 | 1.3473 | 1.2465 |
| 6 | UNGARAN-JELOK2 | 1.6599 | 1.1995 | 1.3473 | 1.2465 |
| **Total** | | **3.9272** | **4.9512** | **3.9852** | **4.2826** |

### *3.3.4 Voltage and Losses Improvement in Central Java at Night*

Prior to the placement of BESS, the average voltage in Central Java Province was 0.9985 pu, and after the placement of BESS the voltage became 1.002 pu. There is an improvement in the voltage profile of 0.0035 pu after the placement of BESS at Jelok substation. Meanwhile, it is found that the losses before the placement of BESS in Central Java Province is 65.28 MW, as seen in Figure 8, and after the placement of BESS the losses is 63.41 MW, as seen in Figure 9. Therefore, there is a reduction in losses of 1.87 MW after the placement of BESS at Jelok substation at night.



```
                                                   DIgSILENT   | Project:
                                                  PowerFactory |
                                                     15.1.7    | Date:  7/4/2024

Load Flow Calculation                                                              Grid Summary
    AC Load Flow, balanced, positive sequence          | Automatic Model Adaptation for Convergence      Yes
    Automatic Tap Adjust of Transformers          No   | Max. Acceptable Load Flow Error for
    Consider Reactive Power Limits                No   |    Nodes                                      1,00 kVA
                                                       |    Model Equations                            0,10 %

Grid: region3          System Stage: region3    | Study Case: Study Case      | Annex:              / 5
Grid: region3          Summary

No. of Substations     93        No. of Busbars       243      No. of Terminals      2553      No. of Lines          190
No. of 2-w Trfs.       37        No. of 3-w Trfs.     5        No. of syn. Machines  37        No. of asyn.Machines  0
No. of Loads           181       No. of Shunts        7        No. of SVS            0

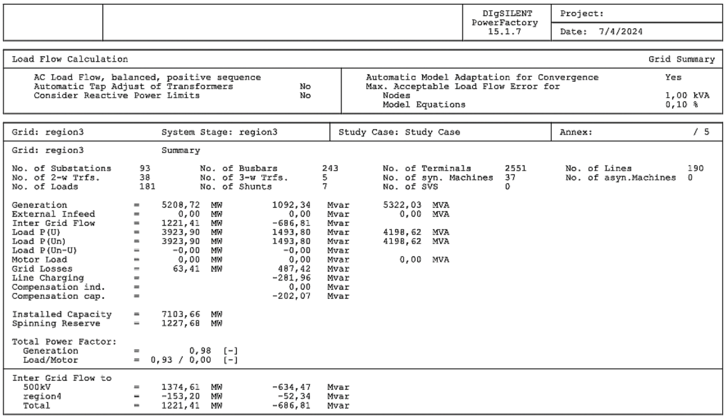
Generation           =    5185,53  MW         1097,23   Mvar     5300,34  MVA
External Infeed      =       0,00  MW            0,00   Mvar        0,00  MVA
Inter Grid Flow      =    1196,35  MW         -694,10   Mvar
Load P(U)            =    3923,90  MW         1493,80   Mvar     4198,62  MVA
Load P(Un)           =    3923,90  MW         1493,80   Mvar     4198,62  MVA
Load P(Un-U)         =      -0,00  MW           -0,00   Mvar
Motor Load           =       0,00  MW            0,00   Mvar        0,00  MVA
Grid Losses          =      65,28  MW          498,52   Mvar
Line Charging        =                        -280,03   Mvar
Compensation ind.    =                           0,00   Mvar
Compensation cap.    =                        -200,99   Mvar

Installed Capacity   =    7003,66  MW
Spinning Reserve     =       0,00  MW

Total Power Factor:
  Generation         =        0,98  [-]
  Load/Motor         =  0,93 / 0,00  [-]

Inter Grid Flow to
  500kV              =    1349,55  MW         -641,74   Mvar
  region4            =    -153,20  MW          -52,36   Mvar
  Total              =    1196,35  MW         -694,10   Mvar
```

**Figure 8.** Losses Before BESS Placement in Central Java Province at Night



```
                                                   DIgSILENT   | Project:
                                                  PowerFactory |
                                                     15.1.7    | Date:  7/4/2024

Load Flow Calculation                                                              Grid Summary
    AC Load Flow, balanced, positive sequence          | Automatic Model Adaptation for Convergence      Yes
    Automatic Tap Adjust of Transformers          No   | Max. Acceptable Load Flow Error for
    Consider Reactive Power Limits                No   |    Nodes                                      1,00 kVA
                                                       |    Model Equations                            0,10 %

Grid: region3          System Stage: region3    | Study Case: Study Case      | Annex:              / 5
Grid: region3          Summary

No. of Substations     93        No. of Busbars       243      No. of Terminals      2551      No. of Lines          190
No. of 2-w Trfs.       38        No. of 3-w Trfs.     5        No. of syn. Machines  37        No. of asyn.Machines  0
No. of Loads           181       No. of Shunts        7        No. of SVS            0

Generation           =    5208,72  MW         1092,34   Mvar     5322,03  MVA
External Infeed      =       0,00  MW            0,00   Mvar        0,00  MVA
Inter Grid Flow      =    1221,41  MW         -686,81   Mvar
Load P(U)            =    3923,90  MW         1493,80   Mvar     4198,62  MVA
Load P(Un)           =    3923,90  MW         1493,80   Mvar     4198,62  MVA
Load P(Un-U)         =      -0,00  MW           -0,00   Mvar
Motor Load           =       0,00  MW            0,00   Mvar        0,00  MVA
Grid Losses          =      63,41  MW          487,42   Mvar
Line Charging        =                        -281,96   Mvar
Compensation ind.    =                           0,00   Mvar
Compensation cap.    =                        -202,07   Mvar

Installed Capacity   =    7103,66  MW
Spinning Reserve     =    1227,68  MW

Total Power Factor:
  Generation         =        0,98  [-]
  Load/Motor         =  0,93 / 0,00  [-]

Inter Grid Flow to
  500kV              =    1374,61  MW         -634,47   Mvar
  region4            =    -153,20  MW          -52,34   Mvar
  Total              =    1221,41  MW         -686,81   Mvar
```

**Figure 9.** Losses After BESS Placement in Central Java Province at Night

## 4. Conclusion

BESS as a medium of energy storage continues to be used extensively in power systems to provide grid services. BESS is increasingly recognized as one solution to improve power system quality and reliability. This study explores the approach of optimum BESS placement and sizing to improve the power quality of the system, i.e. producing a good voltage profile and reduce system losses. This study focuses on Central Java Region 3 system, with Jelok substation as the selected location after several analyses. The optimal BESS installation location is at the Jelok substation after comparing it with other substations, which have high voltage drops and power losses. This substation can improve the voltage and losses profile during peak loads during the day and night. In this study, BESS has been proven effective in improving the voltage profile during the day, as well as nighttime around the Jelok substation which drops due to peak loads. The best utilization of BESS to fix voltage drops at daytime is with a capacity of 25 MWh. Meanwhile, the most optimal capacity of BESS to accommodate for voltage drops at night is 29.84 MWh. There was a 0.14% improvement in the voltage profile after placing the BESS at the Jelok substation during the day. On the other hand, there was also a 1.3% improvement in the voltage profile after placing the BESS at the Jelok substation at night. There was an improvement in losses of 0.71 MW after placing the BESS at the Jelok substation during the day, and 1.87 MW after placing the BESS at the Jelok substation at night.

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