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Battery Energy Storage System (BESS) as a voltage control at substation based on the defense scheme mechanism

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Abstract
Battery Energy Storage Systems (BESS) can improve power quality in a grid with various integrated energy resources. The BESS can adjust the supply and demand to maintain a more stable, reliable, and resilient power system. Connected to the grid, BESS can respond quickly as a voltage regulator on the grid in the event of a voltage drop during peak load or when a disturbance occurs. Thus, the equipment has designed a voltage regulation scheme to prevent voltage drops and poor power quality caused by some rapid voltage fluctuations. This study investigates the role of BESS as a voltage control combined with a defense scheme mechanism at a high-voltage network in Jakarta. ETAP modeling software has investigated several voltage regulation systems with BESS at the substation indications. The results showed that the BESS at Substations can improve the voltage quality on the grid through voltage regulation.

Keywords:
Battery Energy Storage System;
Power Quality;
Under Voltage Relay;
Voltage Regulator;

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INTRODUCTION

The Battery Energy Storage System (BESS) was developed to improve the quality of the electricity network and the electric power services integration of various sources of electrical energy generation and also balances the power supply with the load so that the operating system becomes more stable and more reliable. Most substations in Indonesia have a trend of unstable voltage, while unstable voltage impacts the electricity supply that is too low or too high. Too low voltage can reduce productivity and cause brownouts; on the other side, a too-high voltage hurts equipment life and performance. Voltage optimization can ensure that the system gets an optimal and stable voltage supply through the equipment at the substations.

BESS can increase the operating voltage of the system when the voltage is low, especially during peak load. It also can be operated faster than other devices because BESS only requires a quick response time compared to other devices. It makes BESS able to control voltage fluctuations when faults occur. BESS controls the voltage by releasing electric power to the system when the voltage is lower than the standard setting so that the voltage can increase rapidly under normal and faulty conditions.

The main function of BESS is to store the electrical energy reserves. By storing large amounts of energy in the operating system and releasing it quickly, BESS can improve power quality, reliability, and load stabilization during a disturbance, thereby improving power quality through voltage regulation [1]. The power system generally uses an Under Voltage Relay (UVR) to regulate the voltage. Therefore, BESS's role in controlling the voltage in the power system by combining the UVR mechanism is needed to analyze whether it will affect the reliability of the grid or not. Based on the defense scheme mechanism at the grid system, the study investigates how BESS can support the UVR at the substation and the most significant factors.

When the voltage drops due to disturbances from the power plant, it causes a voltage drop outside the voltage regulation. It causes a decrease in power quality at all locations of the substation. In some cases, the voltage regulation scheme has worked well to repair the system in the event of a disturbance. However, it still harms the performance of the voltage regulation scheme in the form of low operating voltage in some locations [2]. Therefore, BESS is needed for voltage regulation to stabilize the voltage and improve power quality in certain areas on the grid. This study starts with a hypothesis that BESS combined with UVR can regulate voltage and enhance the quality of power.

Under Voltage Relay

Under Voltage Relay is a protection relay used to regulate the system when abnormal conditions occur in the operating system. It uses voltage as a measuring point when abnormal conditions occur in the operating system [3]. To secure and maintain the power quality of the operating system, dispatchers must continually balance supply (power generation) and demand (load) requirements [4]. The imbalance between supply and demand will cause an abnormal operating system. This abnormality is described as follows.

1. If one or more power generators fail, the power supply to the system will decrease, causing a sudden drop in voltage and frequency (power supply is lower than load demand).
2. If there is a large load coming out of the system, it will increase the power supply to the system, which may cause a rising voltage and frequency suddenly (power supply is higher than load demand) [5].

Battery Energy Storage System (BESS)

Battery Energy Storage System (BESS) could be critical in regulating the voltage in the electric power system. By generating and absorbing power quickly to change the nominal voltage and to balance between generator and load (supply and demand), BESS's fast response will provide reliability to the network [6]. With a better quick charge and discharge, if there is a disturbance, BESS will have a good response in improving the quality of power [7][8]. Additionally, BESS can release stored electrical energy and supply it to the grid system during the shortage or peak load by the cheaper electricity cost so the operating system on that grid can be more efficient [9][10]. The basic working scheme of BESS can be seen in Figure 1.

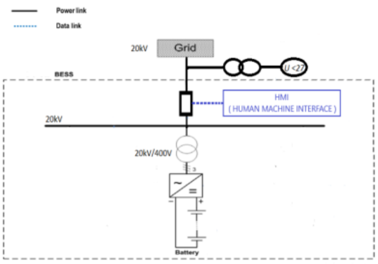

Figure 1. BESS working scheme as a voltage regulator

BESS equipment is grouped according to its function: battery, converter, control, and GIS [11]. The battery system consists of various components that store power, inverters, and converters to convert DC to AC or vice versa, which are helpful during the charging and discharge process [12][13]. The control system required to operate the BESS consists of a Potential Transformer whose function is to read voltage and frequency Under Voltage Relay as a control to enter and exit the BESS system from the system automatically, while for manual use, the Human Machine Interface (HMI) [14][15]. The GIS system itself consists of various types of high and medium voltage equipment, such as Step-up Transformers, which are helpful for increasing the voltage from low voltage AC 400V to AC medium voltage 20kV, Circuit Breakers to connect and disconnect BESS to the load, and power transformers 150kV / 20kV which one function is to connect BESS to the grid [16].

Voltage Regulation

Voltage regulation describes the rules and procedures to ensure reliability and efficiency in power system operation [17]. The voltage regulation in Indonesia's power grid is at 150 kV [18]. This system is stated to be in good operating condition when the voltage is within the normal operating range (150 kV +5% and -10%), except for short time deviations allowed in the range (150 kV + 10% and -20%). Meanwhile, the voltage may be 120 kV and 165 kV during interference conditions.

Frequency operation in Indonesia's power system within the frequency setting is at 50 Hz. The system is declared to be in an excellent operating state when the frequency is within the standard operating range limit (50 ± 0.2 Hz), except for irregularities in a short period allowed in the range (50 ± 0.5 Hz), while during interference conditions, the frequency may at the 47.5 Hz and 52.0 Hz limits.

According to the Regulation of the Minister of Energy and Mineral Resources number 03-year 2007, concerning the Regulation of the Java-Madura-Bali Operating System in the Operational Rules section, some clauses of this Part have summarized the operating principles for a safe and reliable system that must be followed. Part of it also establishes the fundamental obligation of all network users to contribute to safe and reliable operation. It contains voltage regulation limits under normal circumstances and voltage limits in case of disturbance.

The control system will be on when a disturbance occurs in the generator or several generators or IBT (Inter Bus Transformer 500kV/150kV), which creates a fluctuating voltage in the system. Then, UVR will measure the voltage drop that occurs. It measures and records mainly voltages that have dropped and reached 135kV. UVR will command the CB (Circuit Breaker) on the BESS to connect the network directly, thus making the operating system get a better voltage [19].

When the operating system is stable again, the generator or IBT usually operates. The voltage will slowly increase and reach a voltage of 150 kV; after that, the VR (Voltage Relay) will instruct the CB towards BESS to disconnect from the network automatically so the CB direction of BESS can be disconnected manually via HMI. In this case, the voltage has yet to reach 150 kV [17][20].

When the 500 kV operating system or generator falls into blackout, the voltage worsens and reaches 135kV, and VR will work [16]. To overcome voltage fluctuations, BESS is installed as a voltage regulator that can adjust the voltage quickly and still at the permissible limit to avoid power quality degradation [21].

The UVR function for controlling BESS is drawn as in Figure 2. In addition, BESS can be combined with the UVR mechanism. Besides that, BESS can be operated manually via HMI, so it can improve the system voltage and power quality, especially during peak load.

METHODOLOGY

This study was conducted quantitatively by collecting data, modeling, and testing the model. The data was collected from the daily records of 21 Substations in the Jakarta grid system. It is obtained from each substation for three months. Equipment data can be obtained for each substation based on the one-line diagrams available in the operator control room. Data assets and basic data such as name plates on generators, transformers, main equipment, transmission equipment, and other related information have been recorded by the Data Management Team at PT. PLN (Persero) West Java Transmission Unit or UITJBB, Duri Kosambi Service Unit. The data is used to run a power system tool, in this case, ETAP, to test BESS combined with the UVR mechanism at the Substation in Duri Kosambi, West Jakarta. Figure 3 describes how the research was carried out step by step.

The flowchart also explains how to calculate BESS capacity based on load loss and source estimation when a fault occurs, thereby aligning BESS capacity with operating system requirements. When the BESS capacity exceeds the system requirement, it is inefficient because BESS will not work at maximum capacity. On the other hand, if the capacity is lower than the requirement, it will cause a decrease in power quality, and BESS cannot support the system as a voltage regulator well.

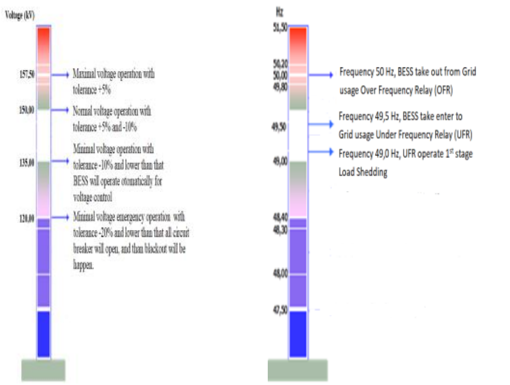

Figure 2. Under Voltage Relay as control voltage and frequency operation for BESS

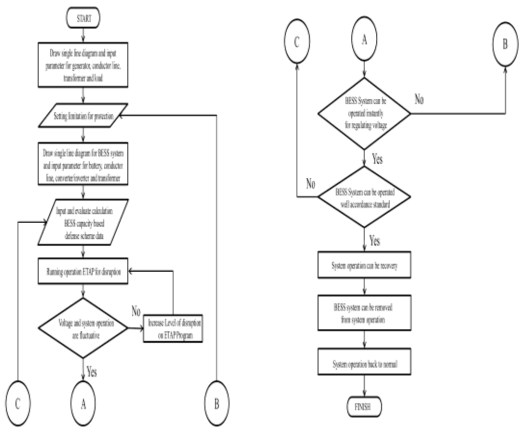

Figure 3. Research flow chart.

Diagram Single Line

Figure 4 describes the Java – Madura – Bali operating system, which focuses on the Lontar-Balaraja 3,4 – Kembangan 1,2 Sub-system in which PT operates. PLN (Persero) P2B – Regional Load Operator of Jakarta and Banten. Three generating units (power plants) and 21 substations operate at 150kV, and 4 IBT 500/150kV are located in Balaraja and Kembangan. The generating units are Lontar Generator Unit 1, unit 2, and Unit 3, serving West Jakarta City, Tangerang City, Tangerang Regency, and South Tangerang City, which have an average load of 1900MW at peak season.

BESS Single Line

Figure 5 shows a model of how BESS is placed at sub-stations in the Lontar-IBT Balaraja 3 and 4 – IBT Kembangan 1 and 2 sub-systems to facilitate the placement and installation of BESS. BESS can be obtained with the existing capacity at the market without adjusting BESS and maximizing land use at the substation operated by PT. PLN (Persero) UITJBB - Duri Kosambi. [23]

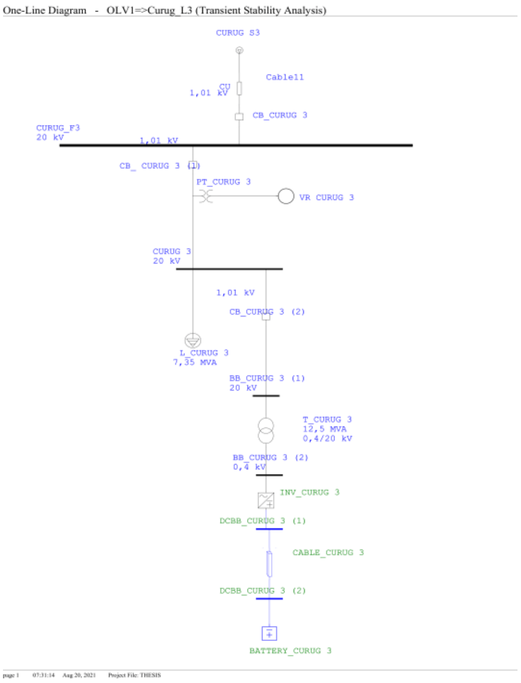

Figure 4. Single line BESS using the ETAP program on Transformer 3 at the Curug Substation

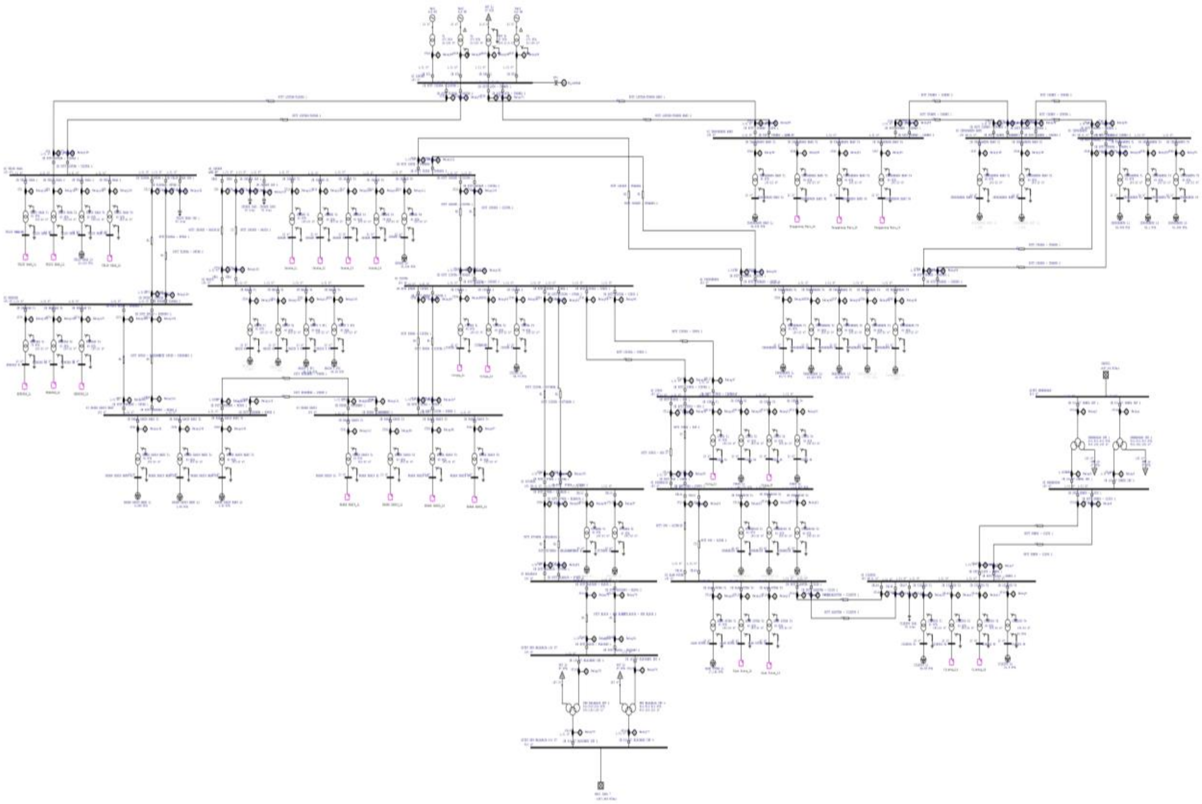

Figure 5. Single Line Diagram of Lontar-Balaraja Sub-System 3,4 - Kembangan 1,2 [22]

BESS will be off after the system voltage becomes normal at 150 kV by re-operation of the IBT on the Balaraja and Kembangan Substations or Lontar power plant. It will exit the system, automatically controlled by setting VR to 150 kV and adding a Time Delay Relay, ensuring stable frequency. For this study, when the voltage value has not met the 150 kV VR setting, the HMI will issue the BESS manually [24][25].

RESULTS AND DISCUSSION

The testing and simulation at the substation have been analyzed using the ETAP program to get a more precise calculation of the Stability and Transient Analyst values. Hopefully, it will become a better test model that can be proposed with a better research conclusion, especially for the impact of the power system.

When the VR is tested by the ETAP program using a temporary simulation for about 9 seconds, for the VR test at variable voltage, the initial voltage before BESS enters is 144.7 kV. When BESS enters the grid via manual control of HMI, the initial voltage is up to 144.7 kV or 100%. After that, it rises to 148.1 kV. In this condition, the system experiences improvement in voltage and power quality, so the system becomes more reliable and stable.

Normal Operating System with BESS

In normal operations with BESS, it will charge the power system's supply, raise the system voltage, and assist its low voltage. Then the voltage will rise, making a better stable power system.

Figure 6 and Figure 7 show the graph of voltage and frequency when the VR tested by the ETAP program calculates a temporary simulation for about 9 seconds. For the VR test on variable frequencies, the initial voltage before BESS enters is at a frequency of 50 Hz. When BESS enters the grid through manual control of HMI, the frequency remains at 50 Hz. The frequency of the use of BESS remains the same. So that BESS is safe to use without adversely affecting the system.

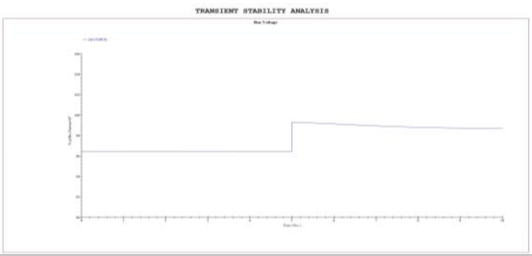

Figure 6. Graph of the voltage on the ETAP in testing the normal scheme of system operation with BESS at the Curug Substation

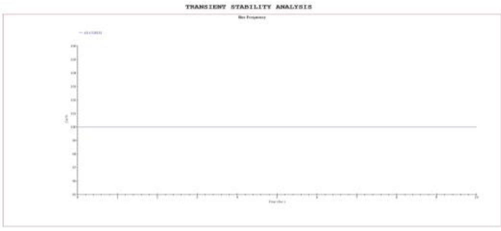

Figure 7. Graph of the frequency on the ETAP in testing the normal scheme of system operation with BESS at the Curug Substation

System Operation when Disturbance without BESS

In the system operation, the voltage will drop drastically when there is a disturbance without BESS. So that the voltage on the system becomes unfit for operation, there must be a reduction in load. This load reduction helps stabilize the system and prevent further damage or outages.

Figure 8 shows the graph of voltage when the VR test by the ETAP program calculates a temporary simulation for about 9 seconds for UVR tests on variable voltages, and the initial voltage before interference is 144.7kV kV. When a disturbance occurs, the voltage fluctuates, decreasing to 130.8kV. In this condition, all loads get a drop in power quality.

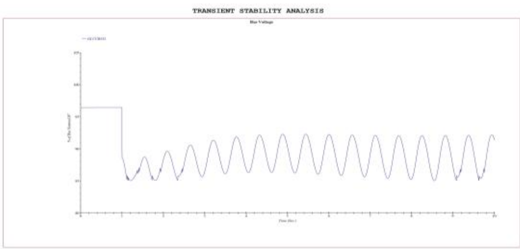

Figure 8. Graph of the stress voltage on the ETAP in the voltage test system operation when interference without BESS at the Curug Substation

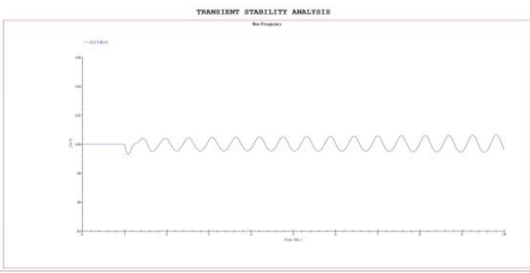

Figure 9. Graph of the stress frequency on the ETAP in the voltage test system operation when interference without BESS at the Curug Substation

Figure 9 shows the frequency graph when the VR test by the ETAP program calculates a temporary simulation for about 9 seconds. For UVR tests on variable frequency, the initial frequency before interference is at a frequency of 50Hz. When a disturbance occurs, the frequency begins to fluctuate. The frequency decreases to 49.75 Hz. In this condition, all loads get a drop in power quality.

System Operation when Interrupted with BESS

In the system operation, when interrupted with BESS, the voltage drops sharply because of an outage in the system. BESS will charge the power system and help raise the system voltage. Then, the voltage will rise again, making the system stable and able to function without requiring a reduction in load. Rapid voltage stabilization reduces the possibility of equipment damage and downtime.

Figure 10 shows the graph of voltage when the VR was tested by the ETAP program using Transient Simulation for 9 seconds for the VR test on a voltage variable. The initial voltage before the disturbance was 144.7 kV. When the disturbance occurred in the first second, the voltage began to drop, dropping to 130.8kV. It triggers the VR operation and the CB on the BESS to connect the BESS to the load. After that, the voltage is stabilized at 144.0 kV. As a result, the burden of power quality degradation on the grid system can be avoided.

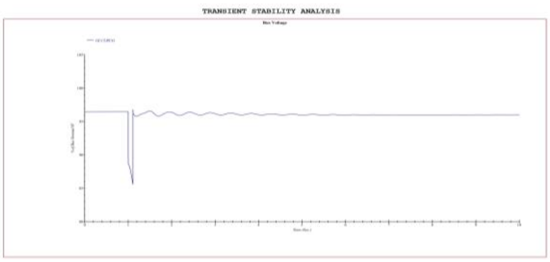

Figure 10. Graph of the voltage on the ETAP in testing the system operating scheme when faulting with BESS at the Curug Substation

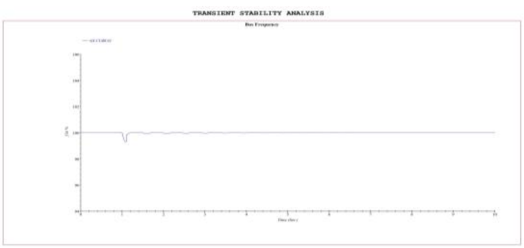

Figure 11. Graph of the frequency on the ETAP in testing the system operating scheme when faulting with BESS at the Curug Substation

Figure 11 shows the graph of frequency when the VR was tested by the ETAP program using Transient Simulation for 9 seconds. The initial frequency before the disturbance was 50Hz for the VR test on variable frequency. When the disturbance occurred in the first second, the frequency dropped to 49.75 Hz. It triggers the VR operation and the CB on the BESS to connect the BESS to the load; the frequency is then stabilized at 50 Hz. As a result, the burden of power quality degradation on the grid system can be avoided.

System Operation when Troubleshooting with BESS

In the system with BESS, it will take over the load to enable troubleshooting until the system functions normally again. Figure 12 shows the voltage graph when the VR test is conducted by the ETAP tool using Transient Simulation for 9 seconds, while the VR test is on a voltage variable, and the initial voltage before the disturbance is 144.7 kV. When the disturbance occurred in the first second, the voltage began dropping to 130.8kV. It commands VR's work and instructs BESS's CB to connect the BESS to the network so the voltage becomes stable at 144.0 kV. At the 5th second, the generator on the operating system starts normally, so the voltage becomes stable at 146.5 kV. When the generator usually starts, BESS is ready to come out from the system.

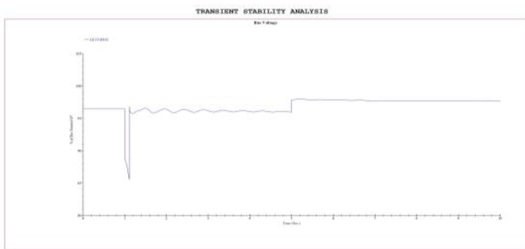

Figure 12. Graph of the voltage on the ETAP in testing the system operating scheme when fault recovery with BESS at the Curug Substation

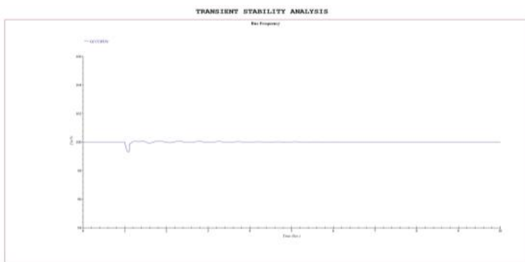

Figure 13. Graph of the frequency on the ETAP in testing the system operating scheme when fault recovery with BESS at the Curug Substation

Figure 13 shows the graph of frequency when the VR test is conducted by the ETAP tool using Transient Simulation for 9 seconds. While the VR test is on a frequency variable, the initial frequency before the disturbance was 50Hz. When the disturbance occurred in the first second, the frequency began to drop to 49.75Hz. It commands VR's work and instructs BESS's CB to connect the BESS to the network so the frequency becomes stable at 50 Hz. When at the 5th-second of time, the generator on the operating system starts normally, so the frequency becomes stable at 50Hz. When the generator starts normally, and the system is back to normal, BESS is ready to come out from the system.

System Operation when Troubleshooting with BESS Normalization

In the system operation, when troubleshooting with BESS normalization, it will take over the load to enable troubleshooting until the system functions normally again. When the source is able to run once more, BESS will be adjusted once more to replenish the power used after finishing its duty.

Figure 14 shows the graph of voltage when the VR was tested by the ETAP program using Transient Simulation for 20 seconds, while the VR test on variable voltage, the initial voltage before the disturbance was 144.7 kV. If the disturbance occurred in the first second, the voltage began to drop to 130.8kV. It initiated the VR in operation mode and started the CB of BESS to connect the BESS to the power network so the voltage becomes stable at 144.0 kV. At the 5th second, the power generation on the grid starts normally to stabilize the voltage at 146.5 kV. At the 9th second, BESS came out when the system was back to normal, so the voltage dropped astray and became stable at 141.6kV. BESS has come out of the system, and the voltage returns to normal.

Figure 15 shows the graph of frequency when the VR was tested by the ETAP program using Transient Simulation for 20 seconds. While the VR test was on variable frequency, the initial voltage before the disturbance was at a frequency of 50Hz. If the disturbance occurred in the first second, the frequency began dropping to 49.75Hz. It initiated the VR in operation mode and started the CB of BESS to connect the BESS to the power network so the frequency becomes stable at 50Hz kV. At the 5th second, the power generation on the grid starts normally to stabilize the frequency at 50Hz. At the 9th second, BESS came out when the system was back to normal, so the frequency was still stable at 50Hz. The results of all ETAP modeling tests can be seen and summarized in Table 1.

Before using BESS, tests show that when there is a disturbance, the voltage and frequency drop to 130.1kV and 49.7Hz. When using BESS as a voltage control, the voltage and frequency are stable at 144.0kV and 50Hz when there is a significant disturbance in the grid system.

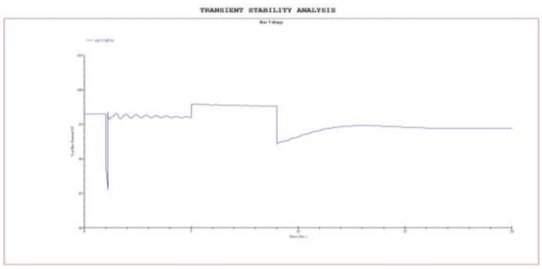

Figure 14. Graph of the ETAP voltage in testing the system operating scheme when fault recovery with normalization BESS at the Curug Substation

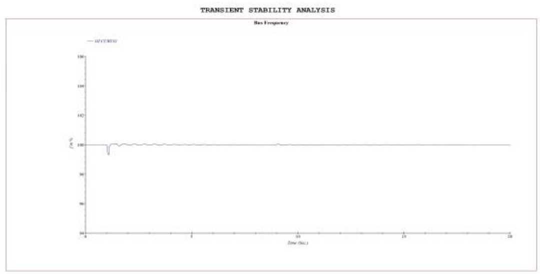

Figure 15. Graph of the ETAP frequency in testing the system operating scheme when fault recovery with normalization BESS at the Curug Substation

Table 1. Test results before and after using BESS at the Curug Substation

Curug Substation 150kV	Frequency before Disruption (Hz)	Voltage before Disruption (kV)	Frequency after Disruption (Hz)	Voltage after Disruption (k)V
Operation System without BESS	50	144.7	50	148.1
Operational BESS as Frequency Regulator test	50	144.7	49.75	130.8
Operational BESS as Back Up test	50	144.7	50	144.0
Normalization Source testing	50	144.7	50	146.5
Normalization BESS testing	50	144.7	50	141.6

When the source of normalization of power generation, the voltage and frequency are stable at 146.5kV and 50Hz. When the BESS comes out of the grid system, the voltage and frequency are stable at 141.6kV and 50Hz. Adding BESS to the network makes the system's power quality stable and reliable under peak load and when interruptions are overcome.

The research has examined before how to maximize the use of BESS from using Proportional Integral Derivatives (PID) to control BESS frequency, using algorithms in controlling BESS, using miniature BESS in frequency regulation experiments, using frequency control in wind-diesel plants, controlling BESS at peak loads, frequency control using BESS in a distributed manner, and various more studies on management financial and financial regulation about which savings when using BESS. Previous research studies have not found titles or discussions about the use of BESS to control voltage using defense scheme mechanisms. And most of them discuss frequency control for BESS. Therefore, this research was chosen.

CONCLUSION

Based on the modeling simulation tests, this study has proven that BESS can work well as a voltage regulator in a power system. BESS can operate quickly to increase the voltage on the grid system, so the decrease in power quality in that grid system can be minimized and even avoided. It supports several previous studies on Battery Energy Storage Systems for Primary Frequency Response. Simulations have been carried out to test BESS as a voltage booster in normal conditions in the network. In this scenario, the HMI can work manually at an initial voltage of 144.7 kV; after that, BESS increases the grid voltage and frequency to 148.1 kV. In this condition, the voltage and power quality are improved to be more reliable and stable. In addition, this study shows that applying BESS can support the UVR mechanism at the substation by increasing the power quality initiated by the UVR control when a disturbance occurs on the grid. The UVR can operate well at the voltage of 135kV, and BESS can control the voltage to recover the system at 144.0 kV. For source normalization tests in case of disturbance, BESS can work well as a voltage regulator to push back both voltage and frequency to the original setting at 5 seconds after the disturbance exists.

This study also shows that BESS can work well as a frequency controller in the BESS Normalization test in case of interference after the 5th second of power interruption. BESS operation as frequency control is still within the standard limits under the Regulation of the Minister of Energy and Mineral Resources number 03-year 2007 concerning the Java-Madura-Bali Operating System rules, so the power quality of that operating system can still operate properly using BESS [17]. Indeed, this simulation and modeling study still has some limitations. The test results can be compared with another software modeling to achieve external validity and accurate measurement. This research is conducted only at one location of the power grid with specific operational characteristics. Further research is recommended to study BESS in several locations, different substation technologies, various loads and demands, and other BESS capacities. To obtain a comprehensive result and an action plan, conducting a financial review of the implementation of BESS as a frequency regulation on the grid is necessary.

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