Study of voltage stability on photovoltaic integration into Lombok power system

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Abstract. Photovoltaic (PV) is known as an intermittent energy source so that the impacts need to be calculated by the developer. In order to ensure the presence of PV does not cause the reliability of the system interrupted, developers are required to perform the stability study before the integration. In this paper, voltage stability study is done by using various PV capacities ranging from 5 MWp to 15 MWp in systems with a capable capacity of 90.79 MW using software ETAP 12.6.0. PV generation is set at the maximum site irradiance where power drop due to weather condition. The analysis shows the system stabilized in less than 50 seconds where the voltage disturbance does not exceed 10% for PV with a capacity of 5 and 10 MWp which is connected to a distribution network. Meanwhile, PV with a capacity of 15 MWp requires load release in order to regain stability.

1. Introduction

The development of the photovoltaic (PV) industry experiences significant developments each year throughout the world, with the level of market demand increasing by 40% annually [1,2]. Likewise, PV developments in ASEAN developing countries have started to grow to use this one of the alternative energy options. In various parts of the world, the phase of change from the use of fossils to other alternative renewable sources is beginning to appear. Given the uncertain conditions of conventional fuel costs and the debate about carbon emissions from the energy sector, a faster rate of PV diffusion may be needed to overcome the challenges of sustainability [3-5]. With the advantages of PV, there are many choices for development, so it is indeed very appropriate to be the focus of future energy development for countries in the world. PV technology nowadays is considered as one of the most suitable dispersed populations in remote places [6].

With the shift of energy generation model from fossils to solar energy, local governments have to make certain rules for installing PV in order to enter the network without interfering the performance of the existing system. To fulfill these rules, we must implement a feasibility study before applying for PV integration. Of the many studies contained in the feasibility study, stability studies are very important to be carried out considering the characteristic of PV which is very dependent on the local area weather condition. The intermittent state of the solar lighting causes the PV plant to change dramatically even from its peak state. A dynamic electrical system model of the PV plant including the inverter characteristics and the resource input is required to simulate the impact of the PV system to the utility grid at the point it is connected to [7].
Power system stability can be generally defined as the ability of the power system after various types of technical disturbances that enable it to be able to survive under normal operating conditions and be able to restore conditions to acceptable conditions [8,9]. Power stability is casually divided into two types, namely angle stability and voltage stability [9].

Voltage control and stability issues are not new to the industry which is not only related to weak systems and long lines but is now also a source of attention in highly developed networks as a result of heavier loads. Voltage instability has a serious potential effect because it may cause the system to collapse. Understanding voltage stability is easier when classified into two types of categories: large-disturbance voltage stability and small-disturbance voltage stability. The system is categorized as having a large-disturbance when there are disturbances such as system faults, loss of load, or loss of generation. It can be studied by using nonlinear time-domain simulations with proper modeling. The second type, small-disturbance voltage stability, is concerned with a system ability to control voltages following small events, such as gradual changes in load. This form can be easily studied with steady-state approaches at a given operating point.

PV panels currently circulating in the world are generally made of thin film and crystalline. In general crystalline silicon solar cells have better transient stability against a large enough response to sudden changes in weather conditions compared to thin films [10]. For this reason, the PV used is the crystalline type considering that this type is used by almost 90% of all existing PV [11]. The PV plant is modeled with three different types of capacities namely 5 MWp, 10 MWp, and 15 MWp given that sufficient grid management would allow up to 35% of the electric production to be intermittent [12]. Each facility is implemented in the same scenario each. The aim of this paper is to investigate the impact of PV into the system stability when the weather changes drastically.

2. Voltage Stability Simulation

2.1. Lombok generation and load profile

The electricity network of Lombok Island consists of a 20 kV distribution system and a 150 kV transmission system. Peak Load occurs at 6 to 10 pm, the average load is at 70% of peak load while not on the peak time. The Lombok system consists mainly of government-owned and private diesel generators.

![Figure 1](image-url) **Figure 1.** This is one part of the Lombok system's single line diagram template where PV plant is placed. PV supports the closest load, which is load A. All substations in this picture have a voltage value of 20 kV.
2.2. PV plant specification and Integration
The location of the PV plant placement is adjacent to the coast area with altitudes between 10 to 80 meters above sea level. At this location point, generally, the slope of the solar module is installed at an angle of 7° to the ground surface to give maximum results taking into account the position of the trajectory of the sun. Similarly, this position has a distance that is fairly close to the integration point, which is only 500 meters towards the GI 1.

The PV plant is designed with a capacity of 5 MWp so that it becomes easier to meet other PV capacity scenarios in the form of multiples of 5 MWp, namely 10 MWp and 15 MWp. The solar module used to construct the PV plant in full can be seen in the solar module profile data shown in table 1.

Table 1. Panel characteristics.

| Panel Characteristics                   | Unit | Value  |
|-----------------------------------------|------|--------|
| Nominal Max Power ($P_{max}$)           | Watt | 260.3  |
| Optimum Operating Voltage ($V_{mp}$)    | Volt | 30.7   |
| Optimum Operating Current ($I_{mp}$)    | Amp  | 8.48   |
| Open Circuit Voltage ($V_{oc}$)         | Volt | 37.8   |
| Short Circuit Current ($I_{sc}$)        | Amp  | 8.99   |
| Series                                  | -    | 20     |
| Parallel                                | -    | 3      |

2.3. Simulation model
The overall simulation uses the ETAP 12.6.0 software which starts with the design of line diagrams of Lombok network system that refer to figure 1. Then, the process before starting the simulation is continued with the PV plant design which is integrated into the 20 kV GI 1. The output voltage generated by PV has a value of 0.4 kV, therefore a step transformer is needed to synchronize the voltage at 20 kV.

Simulations carried out using the largest possible output from the PV plant to see the worst possible impact. Data available in the form of irradiation for one full year (365 days) are sorted to find the daily power potential with the highest value, which occurs on August 21st at 11-12 am with an irradiation level of 854 Wh/m². This condition is an ideal condition that overrides the weather and cloud conditions above the location.

The results observed from this study are how the voltage response and how long the system can recover when the PV supply is lost due to interference. Then, by looking at the results of each scenario, the PV capacity is determined which scenario has more minimal impact on the system when a disturbance occurs. To see the stability of the system and run the simulation, PV is given a disturbance in the form of a line fault that occurs in the first second. Then, from the resulting voltage chart, it will be seen how the system responds after seconds the system loses power supply from PV plant.

3. Simulation Results and Discussion
The first scenario is by looking at the voltage response at the 20 kV GI 1 point when given a line fault, the response is shown in figure 2.
The first simulation was carried out with a 5 MWp capacity of PV integration scenario on the distribution side. The voltage on the GI 1 when the 5 MWp PV has not been released is 19.6 kV. In this scenario, the system loses 3.269 MW of supply abruptly or 3.6% of the total system capacity. In figure 2, the voltage returns stable at 48 seconds and steady at 19.42 kV.

The second simulation is carried out with a 10 MWp capacity PV integration when the system loses a sudden supply of 6,538 MW or 7.2% of the total system capacity. In figure 3, the voltage is seen to be stable at 34.4 seconds, or 14 seconds faster than the first scenario. In this scenario, GI 1 encounters a voltage drop from 19.72 to 19.4 kV. Installing a larger PV capacity has an impact to greater voltage on the GI 1 in normal conditions.

The third simulation is carried out with a 15 MWp capacity PV integration when the system loses a sudden supply of 10,252 MW or 11.5% of the total system capacity. In figure 4, the voltage is seen to be stable at 48 seconds, or 14 seconds faster than the first scenario. In this scenario, GI 1 encounters a voltage drop from 19.72 to 19.4 kV. Installing a larger PV capacity has an impact to greater voltage on the GI 1 in normal conditions.
It can be seen from figure 4 the simulation of the third scenario by integrating 15 MWp capacity shows the voltage falls after a shock that occurs from the time of fault to the 21st seconds. This shows that the system failed to stabilize and with this result, the system needs to be managed after the fault. It can be said that 15 MWp capacity PV needs special attention to be integrated on Lombok distribution side. One way to handle the falling value of voltage is to detach a few loads in the system. To carry out the release of the load, it is very important to prioritize the release of loads as small as possible. Therefore, in the 3rd scenario, the first load discharge test was carried out at the load A area of 1.4 MW, followed by the release of the load B of 18.7 MW.

In figure 5, the results show that the disconnection of load A does indeed have an impact in handling dropping voltage due to the release of PV. However, it can be seen that the voltage chart moves down after passing the 28th second. This shows that the release of load A, which is quite small, cannot restore the stability of the voltage in GI 1. To test how much load must be sacrificed to restore the system to be stable, the closest and smallest load is chosen, namely the load B. Even though there is still a voltage drop, the voltage level after the release of load B is still above the standard system voltage of 10% of the nominal voltage.

A brief summary of the voltage response of the GI 1 when PV is integrated can be seen in table 2. It shows GI 1 voltage condition when the PV is still connected, when it is stable, and the smallest voltage value when instability occurs.

| Scenario                  | Voltage at t = 0 (kV) | Voltage when Stabilizes (kV) | Lowest Voltage at the Time of the Event (kV) | Recovery time (s) |
|---------------------------|-----------------------|------------------------------|--------------------------------------------|-------------------|
| 5 Mwp                     | 19.6                  | 19.42                        | 19.36                                      | 46.21             |
| 10 MWp                    | 19.72                 | 19.4                         | 19.04                                      | 35.61             |
| 15 MWp                    | 19.76                 | -                            | -                                          | -                 |
| 15 MWp & Load A released  | 19.76                 | -                            | -                                          | 28                |
| 15 MWp & Load B released  | 19.76                 | 19.5                         | 19                                         | 26                |
4. Conclusions
Installation of PV without a battery on the power system needs to be carefully treated against the problem of weather factors that can appear abruptly. PV installation on the Lombok power system, which is integrated into GI 1, can be concluded safely to be integrated with a PV capacity of 5 MWp & 10 MWp. Meanwhile, the installation of PV with a capacity of 15 MWp requires special attention. When there is a disturbance in the PV which causes the PV power supply to be detached, a voltage drop can be handled by releasing the load in the substation.

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