Study of Voltage Stability Due to Shading Effects on Photovoltaic Penetration in PKMT Distribution System

N Nabila, G M Bangun, M A Budiansyah, G Alviningsih, A R Utomo
Department of Electrical Engineering, Universitas Indonesia, Depok, Indonesia

E-mail: arutomo@eng.ui.ac.id

Abstract. PV output power is firmly influenced by temperature and solar irradiation that fall on the surface of the PV modules. Shading which cross-wiseing the surface of PV modules is major factor that prevails the degradation of its performance. The shading in PV arrays is caused by the presence of cloud, dust, fog, trees, the shadow near buildings, and so on. As the result of the shading effect, the voltage and current outputs fluctuate which would in turn reducing the efficiency of the PV output. The voltage and current of PV solar cells will drop from partial shading effect experiment which consists of 20%, 40%, 60%, 80%, and 100% shading area. This paper shows the effect of PV system over the voltage stability by variating the shading conditions using simulation by ETAP software 12.6.0.

1. Introduction
The technology developments are so fast and increasingly sophisticated, as well as the economic developments [1-3]. In connection with these developments, they also impact to the electricity generation system which are becoming basic needs in elements of life. Electricity needs also increasing along with era development, while the supply of energy resources are getting depleted. We know that in various parts of world initially use plants which are sourced from conventional non-renewable energy namely fossil energy power plant [2,4]. This fossil energy power plant is very profitable in terms of economy, but does not have a good impact to the environment due to CO2 emission that will pollute the environment [5]. Conventional generation system that still uses fossil fuels are now being reduced to create clean and environmentally friendly energy [5].

Photovoltaic (PV) power is one of the renewable energy that have been used and also suitable in remote places [6]. In its performance, PV utilizes solar radiation where PV is sensitive to sun light and ambient temperature[7]. The use of photovoltaic around the world has grown between 15% and 40% for the last 10 years [4]. Many conditions can affect PV performance, one of which is shadows or could be named shade effects [8]. There are several things that cause shadows such the presence of clouds, fog, smoke, dust, trees, and so on [8]. Photovoltaic modules usually installed on the roof of houses or buildings which have possibility that shadows might block the solar radiation to enter the photovoltaic (PV) surface. The consequence of shading phenomenon is reduce the level of irradiance solar which will affect to the stability of PV performance output such as voltage, current and the efficiency of its performance [8].

In order to PV penetration, there are several studies that should be concerned about. Stability studies are one of the studies that carried out to consider the characteristic of PV which is very dependent on the local area weather condition. As said before, the level of solar radiation is very impactfull to the PV...
plant, eventually could change dramatically from its peak state.

Power system stability generally defined as the ability of power system to achieve an equilibrium state after being dispersed to several disturbances, also be able to restore conditions to acceptable conditions [9]. Power stability is casually divided into two types, namely angle stability and voltage stability [9 - 12].

Voltage stability studies are ability of a power system to maintain the acceptable voltage at all buses in the system under normal operating conditions after being subjected to an interference [9]. Voltage stability classified into two types of categories such large-disturbance voltage stability and small-disturbance voltage stability [13].

In this paper an analysis of voltage stability on photovoltaic penetration in the area of X. The GI PKMT will be carried out by having a solar power plant capacity of 5 MWac, 7.5%. Also besides, this study will be carried out with 6 scenarios to simulate the shading effects and examine the result of the simulation using ETAP software 12.6.0. The scenarios are patterned by the percentage of shading such 100%, 80%, 60%, 40%, and 20%.

2. System Configuration

2.1. System Generation

The electricity network of Lombok Island consists of a 20 kV distribution and a 150 kV transmission system. The Lombok system consists mainly diesel generators. The 150 kV system is comprised of buses named GI S, GI MTG, GI J, GI PKMT, and GI PGBY while the 20 kV system consists the other non-named buses connected to several diesel generators.

2.2. PV plant specification

The PV plant is located in East Lombok Regency, West Nusa Tenggara Province, Indonesia which leads to the coordinates of GI PKMT location are 116°31’35.9”E east longitudes and 8°37’24.3”S south latitudes. Indonesia which has a total installation capacity of 5 MWac 7.5%. All PV plant and all its supporting facilities are built in an area of approximately 80,000 m². The average amount of irradiation of sunlight at a location based on feasibility study is 1,950.4 kWh/ m²/year. The electricity generated by the plant is channelled through a 20 kV distribution network which is built with a total length of 6 km from the PV power plant to the 150 kV GI PKMT.

![Figure 1](a) Photovoltaic cell P-V Curve; (b) Photovoltaic cell I-V Curve

The PV plant is designed with a capacity of 5 MWac, 7.5% which actually means the PV plant capacity is in the amount of 7 MWp. The solar module used to construct the PV plant can be seen in the solar module profile data shown in Table 1. To achieve the desired rating and a capacity of 7 MWp, it is shown a module of 21,840 units is needed. Within these amount PV model units, an area of 8 hectares which is written before is needed for the PV models installation. For each installation capacity of 7 MWp, solar panels with a string coordination of 1,092 sets in a parallel position where each string has 20 units of modules.
This study is simulated by using the ETAP 12.6.0 software which begins with the design of line diagrams of X network system. Afterwards, before the simulation began the process is continued with integrate the PV plant design and battery into the 20 kV GI PKMT. The value of output voltage which is generated by PV is 0.4 kV, therefore it is needed to step up and also to synchronize the voltage at 20 kV. A step up transformer is an electrical device that could carry out. The capacity of the step up transformer is min 1,360kVA. Data for the simulation in the section of irradiation for one full year is sorted to find the daily power potential with the highest value, which is occurs at optimal hours of PV performance in GI PKMT which is at 11.00 am – 12.00 am with an irradiation level of 701 Wh/m².

PV is a DC power supply. To be able to synchronize to the on-grid, conversion of DC power into AC power is required. Therefore, it is necessary to use an inverter where in this simulation, the inverter used has the following characteristics shown in Table 2.

### Table 1. Panel characteristic

| Panel characteristics                  | Value | Unit |
|----------------------------------------|-------|------|
| Nominal Max Power (Pmax)               | 320   | Watt |
| Optimum Operating Voltage (Vmp)        | 37.4  | Volt |
| Optimum Operating Current (Imp)        | 8.56  | Amp  |
| Open Circuit Voltage (Voc)             | 46.4  | Volt |
| Short Circuit Current (Isc)            | 9.05  | Amp  |
| Series                                 | 20    |      |
| Parallel                               | 3     |      |
| Temperature Coefficient Alpha Isc      | 0.06  |      |
| Temperature Coefficient Beta Voc       | -0.03 |      |

Shade effect experiments carried out consisted of variable changes affected by shading ranging from 20%, 40%, 60%, 80%, and 100%. Within these variations of shading simulation, the use of transient stability module on ETAP software is needed.

The differences in the electrical characteristics of the system observed, namely electrical characteristics are the voltage, current, and also output power. The study is focused on how the stability of output voltage characteristics shown due to the shading effect simulations and also due to the battery existence on the PV plant system.

Using the scenario as said at previous paragraph, the simulation is carried out in a continuous graph of stress at the distribution point when shading occurs. The graph shows the effect of shading on voltage stability.

### Table 2. Inverter characteristics

| Inverter characteristics              | Value                  | Unit                        |
|----------------------------------------|------------------------|-----------------------------|
| Efficiency                             | Min 97%                |                             |
| Max input DC power                     | 950                    | kW                          |
| Max input DC voltage                   | 1000                   | V                           |
| Delta MPP range                        | Min 550                | V/integrated                |
| AC nominal power output                | Min 680/578            | kVA/kW per inverter         |
| Nominal AC voltage output              | 380                    | V                           |
| Rated frequency                        | 50                     | Hz                          |
| Power factors (cos phi)                | 0.85 lagging and 0.9 leading |                 |
3. Simulation and Result

Simulation is done by seeing the results of the system simulation using ETAP software 12.6.0. The appearance of the transient simulation is shown in Figure 2. The first scenario is by looking at the voltage response at the 150 kV G1 PKMT point when given shading pattern in the amount of 100% until 20%. Within a 7 MWp capacity PV which also integrate to the battery system scenario, the output PV by the 100% PV contribution without any shading pattern is 98.277 %kV. However, the next scenario is taken with no battery system integration to the PV, the output of 100% PV optimal contribution without any shading pattern is 98.5619 %kV which can be seen in Figure 3.

![Figure 2. The appearance of the transient simulation](image)

The first simulation is carried out with a 7 MWp capacity PV integration scenario with given shading pattern of 80% which means the solar radiation level is in the amount of 561 Wh/m². Also, the PV plant is connected to battery system which has the capacity of 1072 AH with 15 plates of battery. The response is shown in Figure 3. In this scenario, the least output voltage of PV is 93.8847 %kV. According to Figure 3, the voltage returns stable at 20 until 30 seconds. The second simulation is still carried out with a 7 MWp capacity PV integration scenario with shading pattern of 80% given. The difference between the first simulation is the battery is no longer connected to the PV plant integration. Therefore, the least value output voltage of PV is in the amount of 94.1147 %kV. In Figure 3, the voltage returns stable at 20 until 30 seconds.

Furthermore, the simulation is continued with a 7 MWp capacity PV integration scenario with shading pattern of 60% given. The 60% shading pattern means the solar radiation level is in the amount of 421 Wh/m². In this scenario, the PV plant is connected to 15 plates of 1072 AH battery capacity system. The response is shown in Figure 3. According to the output graph shown in Figure 3, the least output voltage of PV within 60% shading pattern is 95.0216 %kV and the voltage returns stable at 20 until 30 seconds. However, the least value output voltage of PV without battery system linked into the PV system is in the amount 95.2514 %kV. The voltage returns stable at 20 until 30 seconds.
The third simulation is carried out with a 7 MWp capacity PV integration scenario with given shading pattern of 40% which means the solar radiation level is in the amount of 280 Wh/m². In this scenario, besides the charge of shading pattern, the PV is connected to 15 plates of 1072 AH battery capacity system. The responses is shown in Figure 3. The output graph shown that the least output voltage of PV and battery integration within 40% shading pattern is 96.074 %kV and the voltage returns stable at 20 until 30 seconds. Besides, the least value output voltage of PV without battery system linked into the PV system is in the amount of 96.3335 %kV and the recovery time of voltage output is at the same time with the battery system integration scenario.

![Figure 3](image)

**Figure 3.** (a) Voltage response summary when shading pattern is given with battery system connected; (b) Voltage response summary when shading pattern is given without battery system connected

Afterward, the simulation is continued with the correspond capacity PV integration scenario used before, yet the given shading pattern is about 20% of optimal solar radiation that is 140 Wh/m². In this scenario, the PV is also connected to 15 plates of 1072 AH battery capacity system. The responses is shown in Figure 3. The output graph shown that the least output voltage of PV and battery integration within 20% shading pattern is 97.1439 %kV and the voltage returns stable at 20 until 30 seconds. However, according to Figure 3, the least value output voltage of PV without battery system contribution in the PV system is in the amount of 97.4184 %kV. The period where the voltage returns stable is at 20 until 30 seconds.

Figure 3 are concise summary of the voltage response at the GI when PV is integrated with battery given 5 scenario, as well as Table 3. It shows GI PKMT voltage condition when the PV is given shading pattern \((t = 5)\), when it is stable, and the lowest voltage value when instability occurs.

**Table 3.** Summary of GI PKMT voltage response due to shading effect and battery system integration.

| Tab Code | Shading Scenario | Cond.         | Voltage of 100% PV | The lowest PV voltage (% kV) | Stable Time (s) |
|----------|-----------------|---------------|-------------------|-----------------------------|-----------------|
| A        | 20% (100% Pv to 80% pv) | With Battery | 98.277            | 93.8847                     |                 |
|          |                 | Without Battery | 98.5619          | 94.1147                     |                 |
| B        | 40% (100% Pv to 60% pv) | With Battery | 98.277            | 95.0216                     | Between 20 – 30 s |
|          |                 | Without Battery | 98.5619          | 95.2514                     |                 |
| C        | 60% (100% Pv to 40% pv) | With Battery | 98.277            | 96.074                      |                 |
|          |                 | Without Battery | 98.5619          | 96.3335                     |                 |
| D        | 80% (100% Pv to 20% pv) | With Battery | 98.277            | 97.1439                     |                 |
|          |                 | Without Battery | 98.5619          | 97.4184                     |                 |
According to the result and graph shown, the installation of PV with batteries does not have a big effect on system voltage. However, with intermittent sun conditions, this voltage instability will often occur every day. For mounting PV capacity & a larger battery, it should be noted because the voltage change can exceed the standard. From this simulation, the installation of PV up to 7 MWp and the battery did not adversely affect the cut-out distribution area.

4. Conclusion
PV installation on the power system needs to be carefully treated against the problem of weather factors which can affect the solar radiation that falls on the PV module surface. GI PKMT used the PV capacity of 7 MWp. So that, the installation of PV with a capacity of 7 MWp requires special attention. From this study, it can be identified that when the PV is exposed to the shading phenomenon according to the scenario that has been created (20%, 40%, 60%, 80%, and 100%), with the 15 plates battery capacity of 1072 AH shows that the installation of PV with battery does not have a big effect on system voltage according to the simulation using ETAP software 12.6.0.

References
[1] Johansson T B, Kelly H, Reddy A K N, Williams R H, Burnham L 1993 Renewable Energy Sources for Fuel and Electricity (Washington DC: Island Press).
[2] Foley G 1995 Photovoltaic Applications in Rural Areas of the Developing World, World Bank Technical Paper Number 304, Energy Series.
[3] Whitaker C, Newmiller J, Ropp M and Norris B, Distributed photovoltaic systems design and technology requirements, Sandia Nat. Labs., Tech. Rep. SAND2008-0946 P, 2008.[Online].Available:http://www1.eere.energy.gov/solar/pdfs/distribute_pv_system_design.pds.
[4] Renewable Energy Policy Network for the 21st Century 2009 Renewables Global Status Report 2009 Update (Paris: REN21 Secretariat).
[5] Byrne J and Toly N 2006 Energy as a Social Project: Recovering a Discourse. in: Byrne J, Toly N, Glover L (eds) Transforming Power: Energy, Environment, and Society in Conflict, (New Brunswick, NJ: Transaction Publishers) pp 1–32.
[6] Siemens 2010 PSS®E: Transmission System Analysis and Planning. [Online] Available at: http://www.energy.siemens.com/hq/en/services/power-transmission-distribution/power-technologies-international/software-solutions/pss-e.htm [Accessed 20 April 2019]
[7] Tiandho Y, Sunanda W, Afriani F, Indriawati A, Handayani T P 2018 Accurate model for temperature dependence of solar cell performance according to phonon energy correction Latvian Journal of Physics and Technical Sciences 55 pp. 15-25
[8] Kawamura H, Naka K, Yonekura N, Yamanaka S, Ohno H and Naito K 2003 Simulation of I-V Characteristics of a PV module with shaded PV cells Solar Energy Materials and Solar Cells 75 pp. 613-621.
[9] Kundur P, Balu N J and Lauby M G 1994 Power System Stability and Control (New York: McGraw-Hill).
[10] Taylor C W 1994 Power System Voltage Stability (New York: McGraw-Hill).
[11] Gallegos and Carlos D R 2015 Analysis of the Stationary and Transient Behavior of a Photovoltaic Solar Array: Modeling and Simulation (Germany: Ulm University).
[12] Antonio L and Hegedus S 2011 Handbook of Photovoltaic Science and Engineering, Second Edition (US: John Wiley & Sons, Ltd).
[13] Pavella M D, Ernst and Ruiz-Vega, D 2000 Transient Stability Of Power Systems: A Unified Approach to Assessment and Control (London: Kluwer Academic Publishers London).

Acknowledgement
This research is funded by research grant of HIBAH PITTA B 2019 No. KB-0695/UN2.R3.1/HKP.05.00/2019 from Universitas Indonesia.