Investigation of Photovoltaic Hosting Capacity Using Minimum Generation Operation Approach

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Article Info

Article history:

Received Jun 11, 2023
Revised Sep 12, 2023
Accepted Sep 29, 2023

Keywords:

Distributed energy generation
Hosting capacity
Photovoltaic
System stability

ABSTRACT

Photovoltaic (PV) have become a priority renewable energy source to be developed in Indonesia to achieve new and renewable energy (NRE) target of 23% in 2025 and 31% in 2050. The operation of a significant number of rooftop PV can also change the type of power system operating configuration to Distributed Energy Generation (DEG). The majority of DEGs which are NRE generators are capable of causing new problems because of their intermittent nature. Hosting Capacity is a high penetration limit for NRE without causing problems and limits on operational violations. The hosting capacity method used is based on the generator's minimum operation. In the test system consisting of 3 power plants such as hydro power plant, coal power plant, and geothermal power plant, the PV capacity that can be injected into the system is 139.1 MW. With PV injection based on hosting capacity, the system becomes better with the same average voltage profile as before PV injection, namely 0.991 p.u. System stability by reviewing the frequency, rotor angle, and rotor speed, the system after PV injection is better than before PV injection.

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1. INTRODUCTION

Climate change is currently a global problem that poses a challenge to sustainable development throughout the world. According to the Intergovernmental Panel on Climate Change (IPCC), human activities such as excessive burning of fossil energy and greenhouse gas emissions are the main causes of climate change [1]. The Paris Agreement exists and binds all countries to achieve common goals with ambitious efforts to combat climate change and achieve net zero emissions (NZE). One way is to abandon fossil power plants such as coal power plant and make an energy transition. The energy transition is a way to transform global energy from fossil-based energy into energy that is environmentally friendly and produces no carbon emissions [2].

Indonesia has a total potential for new and renewable energy (NRE) for electricity generation of 442 GW with the greatest potential in solar energy of 207.8 GW [3]. Solar energy is one of the fastest growing energy sources in the world [4]. The advantage of this technology is that the solar modules used can be installed in almost any location exposed to sunlight [5]. The potential for solar energy in the tropics that cross the equator is around an average of 4.8 kWh/m2/day [6]. The location of Indonesia which is on the equator theoretically will always be exposed to the sun for 10-12 hours a day and almost all parts of Indonesia will receive a relatively even intensity of radiation. This condition is feasible enough to be utilized as a source of solar energy. Solar power plants have also become a priority for renewable energy sources to be developed in Indonesia to achieve the NRE target of 23% in 2025 and 31% in 2050 [7].

Various efforts have been made to accelerate the growth of the use of NRE where one of the priority programs is the construction of a rooftop photovoltaic (PV) [8]. Rooftop PV is planned to be installed in government buildings, public facilities, industry, factories, and residents' homes. The operation of a significant number of rooftop PV can also change the type of power system operating configuration to Distributed Energy Generation (DEG). DEG allows the load to be supplied from a nearby energy source without going through a transmission or distribution line. This configuration can increase system reliability, operating flexibility, improve power quality, and reduce losses [9].

However, the majority of DEGs which are NRE generators are capable of causing new problems. Over the next few decades, the global energy system will undergo significant transformation owing to the rapid Variable Renewable Energy (VRE) development and widespread electrification toward carbon neutrality for compliance with the Paris Agreement [10]. Consequently, energy production will become increasingly dependent on weather and climate variability. Fluctuations in VRE generation cause difficulties at various time scales with respect to load balancing at the grid scale [11]. Future energy systems need to be designed for mitigating this variability at all timescales.

Intermittent NRE or VRE generators such as PV have the characteristic of depending on the power supply to the weather. PV causes a positive net load ramp when the sun sets, and a negative net load ramp when it rises, leading to the well-known 'duck curve' [12]. As net load variability and uncertainty caused by VRE keeps increasing, power systems require more flexible generation or responsive demand resources to balance the load [13]. A large amount of power fluctuation can result in a stable system frequency disturbance. Therefore, it is necessary to calculate the NRE generating capacity that may be added to the power system without disrupting its operational stability [14]. Determination of the location of distributed generators must also be considered so as to maximize the benefits obtained.

Hosting Capacity is a high penetration limit for NRE without causing several problems and operating violations such as: under-limit voltage, excessive network losses, overload on transformers and feeders, protection failures, and harmonics that exceed international standard limits [15]. This research will use the hosting capacity method to evaluate and increase the maximum NRE capacity limit that is allowed to enter the system without disturbing the system stability.

2. RESEARCH METHOD

2.1 Hosting Capacity Theorem

Hosting Capacity (HC) is defined as the maximum number of distributed generators integrated into the distribution network. Where, system performance reaches unacceptable limits according to customer service standards [16]. HC is considered as a statement of power system orientation [15]. Hosting Capacity Coefficient (HCC) is defined as the ratio between the energy limitation and the installed capacity above the HC core. HCC can also be used to compare variation schemes for active power limitation [15].

The basic concept of Hosting Capacity is a concept in seeing the limitations of integration of renewable energy seen in the performance index. According to [17], hosting capacity is the maximum amount of additional electric vehicle capacity that does not affect performance indices, such as voltage, network thermal, overcapacity of transformers, but only limited to voltage. Paper [15,18-19], Hosting capacity is a curve that limits the addition of acceptable DEG capacity based on performance indication criteria. In Paper [20-21], hosting capacity is the maximum limit for DEG penetration with controllable performance limit indicators. Paper [22-24], hosting capacity is the optimal lower limit and limit based on the bus voltage uncertainty scenario. Power system stability [25] can be classified into voltage stability, frequency stability, and rotor angle stability. Stability in question is to maintain the system to work properly. This classification aims to identify any disturbances that can cause the system to become unstable.

The method used to calculate the hosting capacity is to calculate the minimum operation of the existing power plants in the system. Hosting capacity for VRE power generation capacity is calculated based on the difference between the power generation capacity of the system and the minimum operation of the generator in the system. In this study, an approach will be taken with distributed VRE power plants based on the hosting capacity value obtained.

$$HC = GP - Gen_{min} \tag{1}$$

where HC is hosting capacity, GP is generating power, Gen_{min} is generator operating minimum.
In general, each generator has limitations in minimum operation with Gen_{min} assumptions used are as follows based on usual generator manual:

- Hydro power: 40% capacity
- Coal power: 65% capacity
- Geothermal power: 80% capacity
- Gas power: 85% capacity

The flowchart of this research can be seen in Figure 1, in this flowchart a simulation was carried out on the test system with the addition of PV equal to the hosting capacity value obtained from the calculation results. The PV penetration that was tested was with scattered PV. From these results, the effect on the system will be analyzed to obtain a system that remains stable when there is intermittent PV penetration. The final result of this research is a hosting capacity value to get an evaluation and increase in the maximum capacity of NRE generators that are allowed to enter the system.

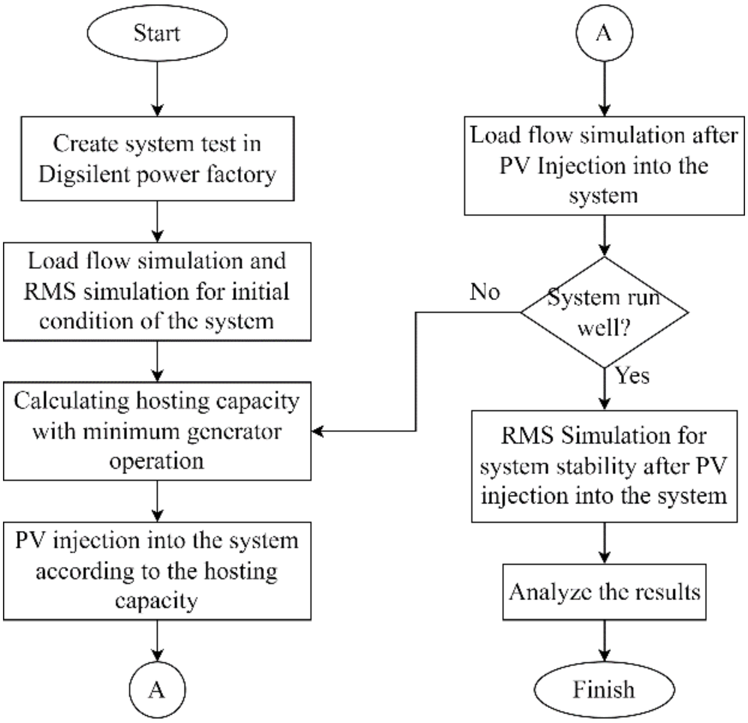


Figure. 1. Flowchart of minimum generation operation approach

2.2 System test modeling

The test system used is as shown in Figure 2. This system consists of 3 different existing power plants, namely coal power plant, hydro power plant and geothermal power plant. For the hosting capacity test, penetration will be added to the load centers with the capacity according to the results of the hosting capacity calculation. The load assumptions used so that the system approaches the real system are loads 1 and 5 as residential loads, load 3 as commercial loads, and load 7 as industrial loads.

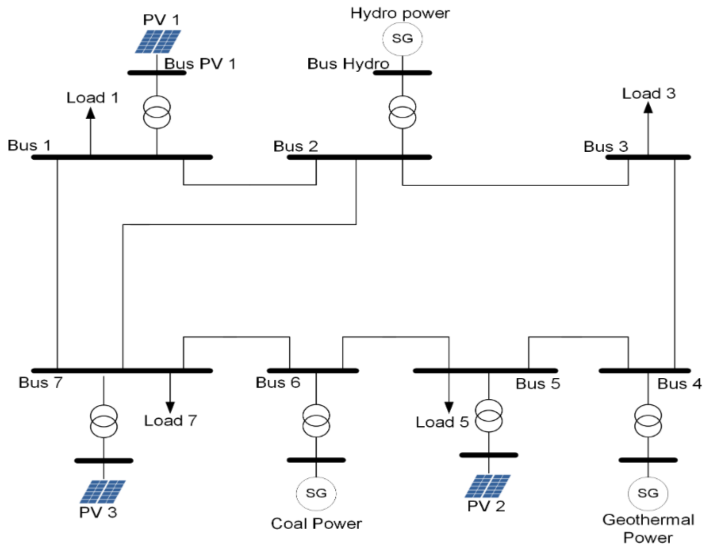


Figure 2. System test

The load curve characteristics used as assumptions in the test system are load data for 2020 in Indonesia, with an average of 1 year. The data presented is the average peak load time. So that the data is used as a characteristic of the load curve. The characteristics of the load curve are divided into residential loads, commercial loads, and industrial loads as shown in Figure 3.

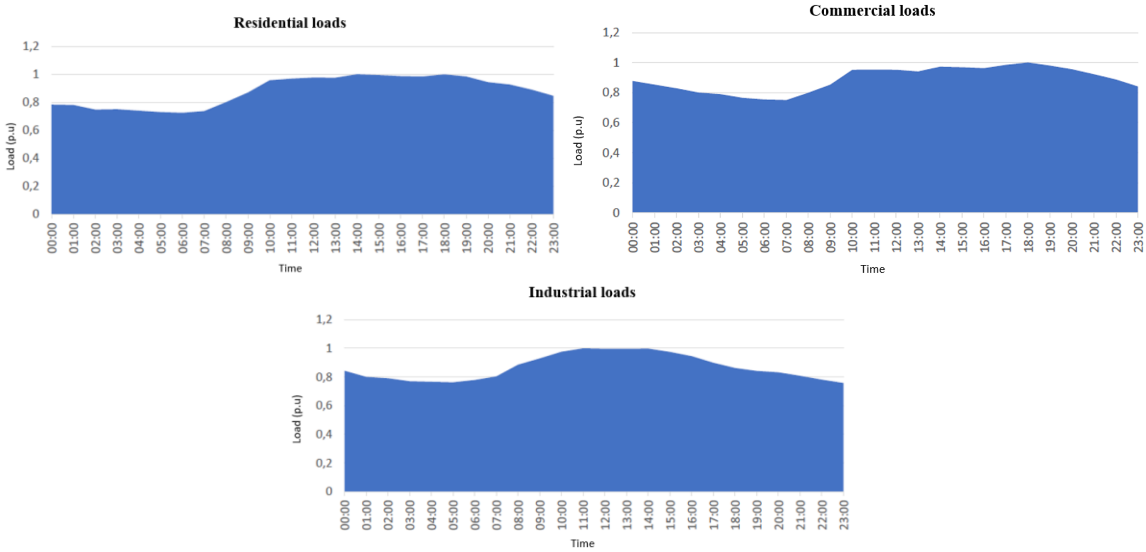


Figure 3. The load curve characteristics of load data for 2020 in Indonesia

The characteristics of the PV curve used are based on measurement points on indonesiasolarmap.com. At the point of the measurement results, an approach is used to be input as a parameter for the characteristics of solar panels based on the load profile category, namely residential, commercial and industrial. The feeders used are implemented in different types of load characteristics.

3. RESULTS AND DISCUSSION

The test system in Figure 5 will apply the hosting capacity method to evaluate and increase the maximum NRE capacity limit that is allowed to enter the system without disturbing the system stability. This evaluation will be carried out by comparing the system before the PV penetration with the system after the PV penetration is dispersed. The simulation will be carried out using the Digsilent Power Factory software.

3.1 Hosting capacity

In the test system used there are 3 different types of power plants, namely coal power, hydro power, and geothermal power. Hosting capacity is calculated using Equation 1.

- Hydro power (170 MW)

$$Gen_{min} = 40\%\ x\ GP \qquad HC = GP - Gen_{min}$$
$$Gen_{min} = 40\%\ x\ 170\ MW \qquad HC = 170 - 68$$
$$Gen_{min} = 68\ MW \qquad HC = 102\ MW$$

- Geothermal power (66,5 MW)

$$Gen_{min} = 80\%\ x\ GP \qquad HC = GP - Gen_{min}$$
$$Gen_{min} = 80\%\ x\ 66{,}5\ MW \qquad HC = 66{,}5 - 53{,}2$$
$$Gen_{min} = 53{,}2\ MW \qquad HC = 13{,}3\ MW$$

- Coal power (68 MW)

$$Gen_{min} = 65\%\ x\ GP \qquad HC = GP - Gen_{min}$$
$$Gen_{min} = 65\%\ x\ 68\ MW \qquad HC = 68 - 44{,}2$$
$$Gen_{min} = 44{,}2\ MW \qquad HC = 23{,}8\ MW$$

So that the total PV capacity that can be injected according to the hosting capacity in the test system can be seen in Table 1 is 139.1 MW.

Table 1. Hosting capacity

Power plant	Generating Power (MW)	Generator operating minimum (MW)	Hosting Capacity (MW)
Hydro power	170	68	102
Geothermal power	66,5	53,2	13,3
Coal power	68	44,2	23,8
	Total		139,1

3.2 System simulation before PV injection

The test system that has been created will be simulated to describe the initial conditions of the system. The simulation carried out is load flow aiming to see the voltage profile of the system. Based on the simulation results in Figure 4 it can be seen that the voltage is under normal conditions with an average of 0.9916 p.u. That way the designed test system has been running well and normally.

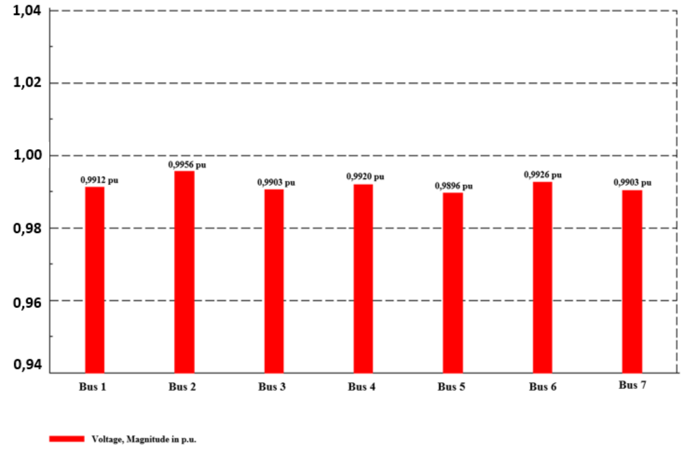


Figure 4 Voltage profile before PV injection

Furthermore, to see the stability of the system, an RMS simulation is carried out with a digsilent power factory. The stability of the system is tested by being given a short circuit interruption for 10 seconds. Then review the frequency, rotation speed, and angle of the rotor of the generator when experiencing the disturbance. The graph of frequency when disturbance occurs is shown in Figure 5, the graph of the rotor angle and rotor speed when disturbance occurs is shown in Figure 6.

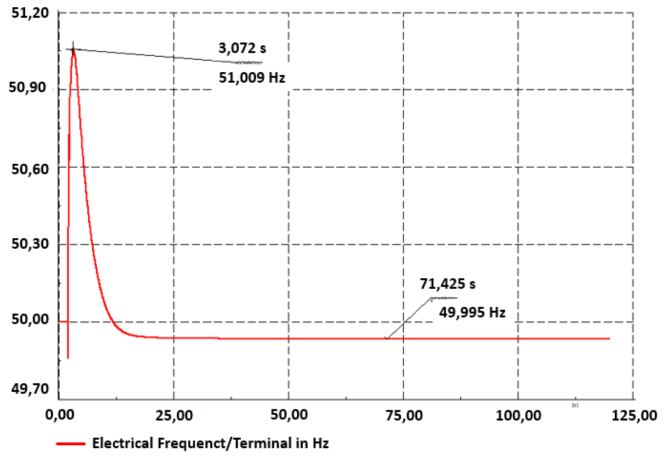
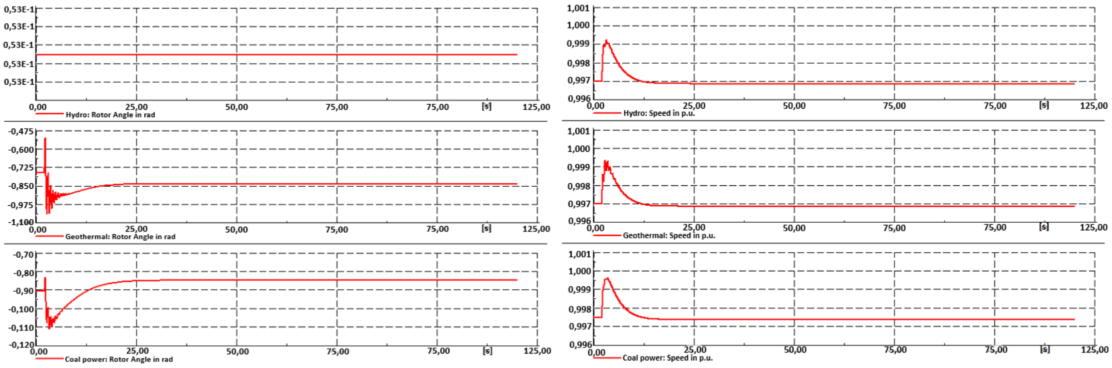


Figure 5. System frequency before PV injection

The system frequency when a disturbance occurs increases to 51.05 Hz, then after the disturbance disappears the frequency on the system returns to stability. However, the value of this frequency stability has decreased slightly, from before the 50 Hz disturbance to 49.935 Hz. With that value the system frequency is still within reasonable limits.



(a) Rotor angle (b) Rotor speed

Figure 6. System stability before PV injection

Rotor angle and rotational speed on hydro power and geothermal power are able to remain stable even though the system has experienced disturbances. When a disturbance occurs, the rotor angle and rotational speed fluctuate slightly but can return to stability after the disturbance is removed. However, the value of the rotor angle before and after the disturbance slightly changed for geothermal power, the value decreased, while for coal power, the value increased. The value of the rotor angle and rotational speed of the two generators are still within reasonable limits so that the system continues to run normally.

3.3 System simulation after scattered PV injection

After injection of PV at the load centers in the system, a simulation will be carried out to see the condition of the system. During the load flow simulation, the voltage profile of the system is obtained as shown in Figure 7. Voltage values at all buses in this system are at fair value with an average of 0.9919 p.u. When compared with the system voltage profile before and after PV injection, it does not show a significant difference. So that the system after PV injection works properly and normally.

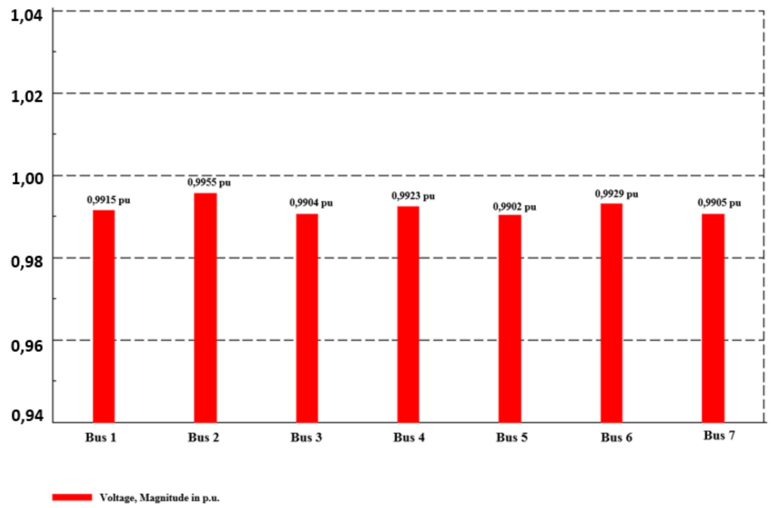


Figure 7. The voltage profile after PV injection is spread out

Furthermore, to see the stability of the system, an RMS simulation will be carried out using the digsilent power factory. This simulation is carried out by giving a short circuit disturbance to the system. Then look at the condition of the frequency, rotor angle, and rotor speed after experiencing the disturbance. The frequency graph can be seen in Figure 8, the rotor angle graph and the rotor speed can be seen in Figure 9.

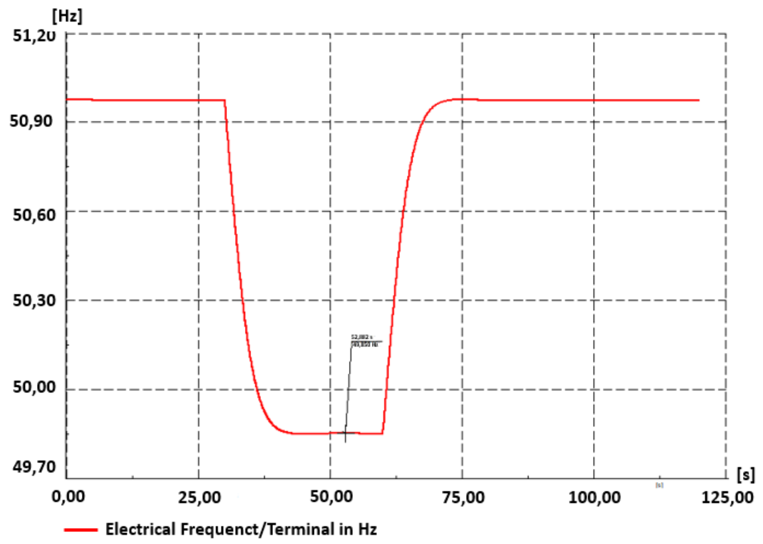
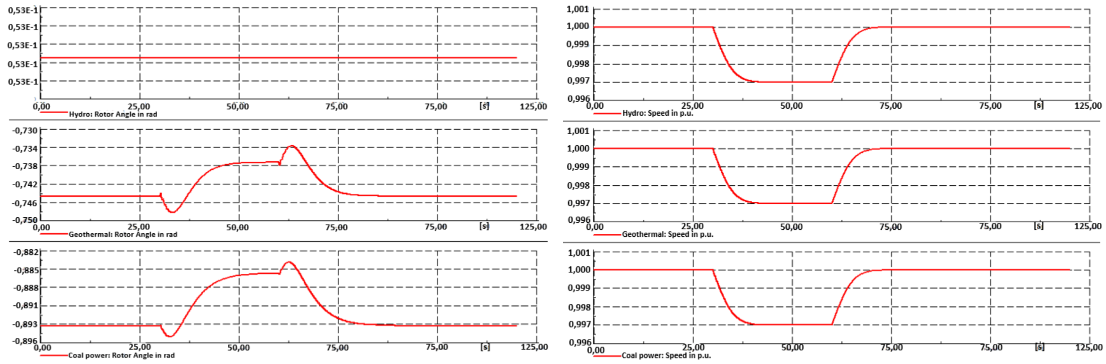


Figure 8. The system frequency after PV injection is spread out

The system frequency when a disturbance occurs drops to 49.85 Hz, then after the disturbance disappears the frequency on the system returns to stability. After a few seconds the frequency value returns to normal to be the same value as before the disturbance, namely 50 Hz. When compared to before the PV injection, the system with distributed PV injection has a better frequency value.



(a) Rotor angle (b) Rotor speed

Figure 9. System stability after PV injection

The rotor angle and rotor speed on all generators are able to remain stable even though the system has experienced disturbances. When a disturbance occurs, the rotor angle fluctuates slightly but can return to stability after the disturbance is removed, while at speed the rotor only experiences a slight decrease in speed and returns to its initial speed after the disturbance is gone. The value of the rotor angle and rotational speed of the two generators are still within reasonable limits so that the system continues to run normally. When compared before PV injection with after PV injection, the conditions of the rotor angle and rotor speed were better after PV injection.

4. CONCLUSION

Hosting capacity is the maximum penetration limit for NRE generators without causing disruption to the system. The hosting capacity method used is based on the generator's minimum operation. The following are some conclusions obtained after applying the hosting capacity to the test system which consists of 3 different power plants. With the hosting capacity method used for 3 power plants, namely 170 MW Hydro power plant, 66.5 MW Geothermal power plant, and 68 MW Coal power plant, the maximum penetration capacity of NRE generators is 139.1 MW. Based on the comparison after and before PV injection in the test system, the voltage profile obtained is the same, namely with an average of 0.991 p.u. In testing system stability by reviewing frequency, rotor angle, and rotor speed, the system after PV injection is better than before PV injection. That way it can be concluded that using the hosting capacity method by considering limitations such as voltage, line loading, harmonics and reverse power flow in accordance with voltage distribution quality standards. The result show based on the minimum operation of the generator can increase stability and be able to make the system better.

ACKNOWLEDGEMENTS

The authors would like to thank Universitas Andalas for funding this research through the RPT scheme, with contract no: T/56/UN.16.19/PT.01.03/Energi-RPT/2023.

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