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Frequency stability and under frequency load shedding of the Southern Sulawesi power system with integration of wind power plants

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Abstract. The Government of Indonesia is encouraging investments in renewable energy based power plants in Indonesia, including wind power plants (WPPs). Two large WPPs in the Southern Sulawesi interconnected power system are Sidrap WPPs and Jeneponto WPPs. Both Sidrap WPP and Jeneponto WPP are the largest WPPs in Indonesia and they account for significant contribution for the Southern Sulawesi power generation mix. Considering the intermittency characteristics of WPPs and system's failure probability, therefore it is essential to assess the system's stability after their integration. This work evaluates the frequency stability of the Southern Sulawesi interconnected power system with the integration of both Sidrap WPPs and Jeneponto WPPs.

1. Introduction

Presently, the demand for electricity energy in Indonesia is increasing rapidly. Indonesia's electricity consumption is quite high that it can become a great problem if the power supply is not in line with the electricity demands [1]. The electrical energy production in Indonesia is now still dominated by fossil-fuel (non-renewable) generation, whereas its availability is decreasing. This has prompted the Government of Indonesia to encourage investments to build power plants in various parts of Indonesia, including the development of wind power plants (WPPs) in several areas. Two large WPPs in the Southern Sulawesi interconnected power system in Indonesia, i.e. Sidrap WPPs in Sidrap regency and Jeneponto WPPs in Jeneponto regency, in South Sulawesi province. Both Sidrap WPPs and Jeneponto WPPs are the largest WPPs in Indonesia and they account for significant contribution for the Southern Sulawesi power generation mix. The capacity for Sidrap WPPs are 75 MW [2] and Jeneponto WPPs are 72 MW [3]. Considering their large penetration into the current Southern Sulawesi power system and the WPPs intermittency characteristic, it creates more challenges to the operational and stability of the system [4-8]. Figure 1 and figure 2 show the wind energy potential at Sidrap and Jeneponto regencies, respectively [9]. As can be seen from figure 1 and figure 2, the wind speed at several areas in Sidrap and Jeneponto are above 7 m/s.

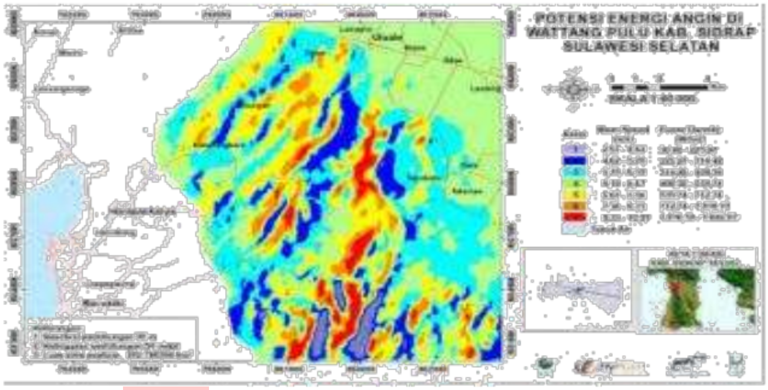

Figure 1. Wind energy potential at Sidrap Regency [8]

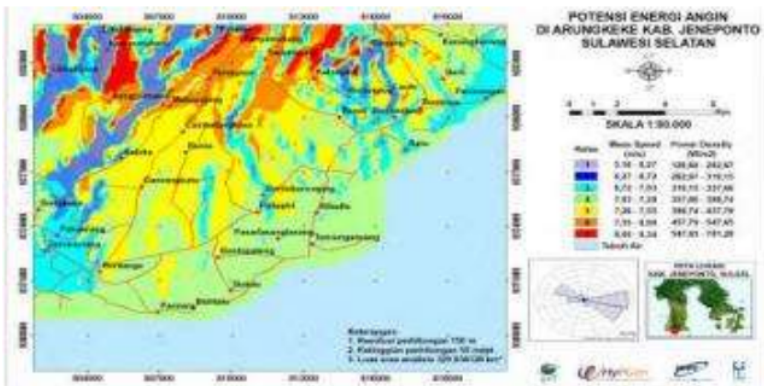

Figure 2. Wind energy potential at Jeneponto Regency [9]

The Southern Sulawesi power system consists of several different power plants with different high voltage transmission rating, that are 275 kV, 150 kV, 70 kV and 20 kV. The average increase of load demand on the Southern Sulawesi system is 11.5% per year according to Power Supply Business Plan of PT. PLN (Persero), the Indonesian State Electricity Company [10]. Hence, this study assesses the frequency stability of the Southern Sulawesi interconnected power system and how is the system's performance when Sidrap WPPs and/or Jeneponto WPPs are suddenly out of the system.

2. Frequency stability

In an electric power systems, frequency is an indicator of the balance between the power generation and the total load of the system. System frequency will decrease if there is a shortage of generation or overload. Large frequency drops can result in successive failure of generator units that may cause total system failure [11]. The partial load shedding by using frequency or voltage relay can prevent the frequency or voltage drop and return it to normal stable condition [12, 13].

One of the characteristics of electric power system that is very essential to be maintained is the frequency stability. The importance of sustaining frequency is closely related to the efforts to provide a quality energy source for the consumers. Supply of energy with a good quality of frequency will avoid damage for consumer equipment. Frequency stability according to IEEE/CIGRE Joint Task Force on Stability Terms and Definitions is the ability of a power system to preserve steady system

frequency within specified operational limits after the system is being upset [14]. Hence the system is said to have
frequency instability when the system is incapable of restoring the frequency within the limit which is caused by a considerable inequity between power supply and load demand [15]. The frequency instability occurs in the form of frequency deviation which is an effect of significant imbalance between the power supply and load [16]. One way to enhance frequency stability is by joint regulation of various power electronic devices [17].

Frequency control is not merely to satisfy the customer solely, but this action also aims to maintain the stability of the system [18]. The frequency of the system is proportionate to the gyratory velocity of the generator directly, where its correlation can be seen in Eq. (1) as follows [19],

$$f = \frac{\mathrm{p+n}}{60} \tag{1}$$

Furthermore, Eq. (2) informs the relationship between mechanical torque (T_m), electric torque (T_e), total inertia moment of the rotor (J), and angular acceleration of the rotor ($\frac{\mathrm{d^2\theta m}}{\mathrm{dt^2}}$) as [18],

$$J\ \frac{\mathrm{d^2\theta m}}{\mathrm{dt^2}} = T_a = T_m - T_e \tag{2}$$

There are several steps to be done when the systems frequency drop below the setting value, such as:

- Increase the total amount of energy supplied to the system by adding a working generating unit.
- Utilizing the Load Frequency Control or LFC facility that controls the rotation of the generator in accordance with the load fluctuations. When the load increases, LFC will give indication to provide more fuel for the generating unit to generate more energy as needed by the load.
- When the generating unit is fully operational, it is necessary to reduce load through under frequency load shedding (UFLS) scheme with under frequency relays (UFR) that work under specific circumstances.

3. Results and analysis

In this study, the simulation is performed to observe the frequency performance of the Southern Sulawesi power system when the Sidrap WPPs and the Jeneponto WPPs are already interconnected into the existing system. The system's dynamic is modelled in detail including the WPPs with frequency regulator. This study assesses the frequency stability if a fault occurs at the Sidrap WPPs substation, the Jeneponto WPPs substation and if both WPPs are suddenly disconnected from the system.

Figure 3 and figure 4 show the system's frequency at all main substations if a fault happens at Sidrap WPPs substation and causing Sidrap WPPs out of the system. Figure 3 and figure 4 show the system's frequency at 275 kV buses and 150 kV buses, respectively. The initial frequency decreased to 49.24 Hz at 9.11 seconds and then rises to a stable state of 49.63 Hz. This happens because when the Sidrap WPPs are disconnected from the system, the system frequency drops, but the governor of another generator responds to this frequency deviation so as to perform a speed drop that resulting in the frequency slowly return to its steady state.

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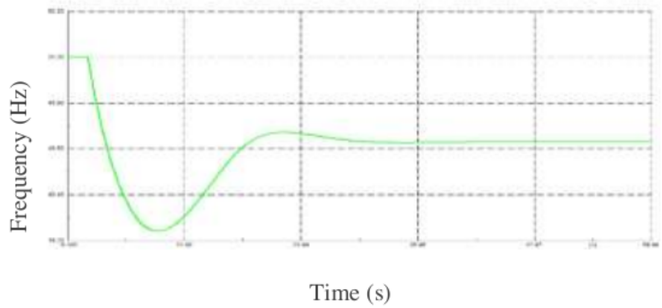

Figure 3. System's frequency performance if Sidrap WPPs are out of the system at 275 kV buses

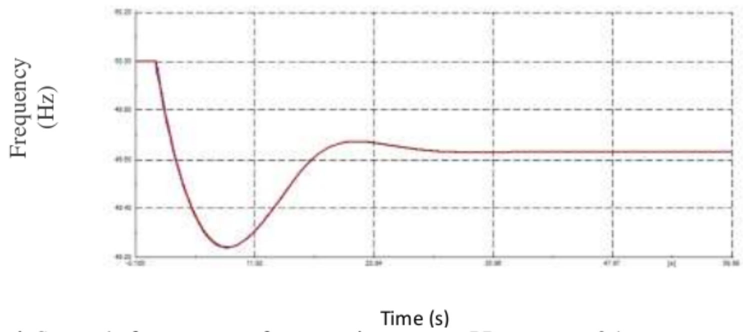

Figure 4. System's frequency performance if Sidrap WPPs are out of the system at 150 kV buses

Figure 5 and figure 6 inform the frequency of all main substations, showing that when the Jeneponto WPP is suddenly disconnected from the system. The initial frequency decreased by 49.03 Hz at 10.19 seconds and then rises up to the steady state (stable) i.e. 49.62 Hz. Similarly to the Sidrap WPPs case, this happens because when the Jeneponto WPPs are disconnected from the system, the system frequency falls, where the governor of the other generator responds to add generation to handle this decrease in frequency.

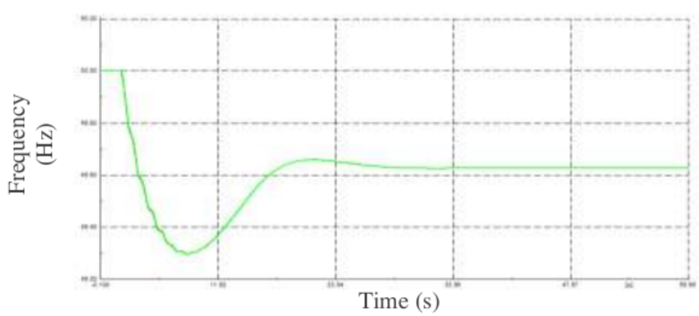

Figure 5. System's frequency performance if Jeneponto WPPs are out of the system at 275 kV buses

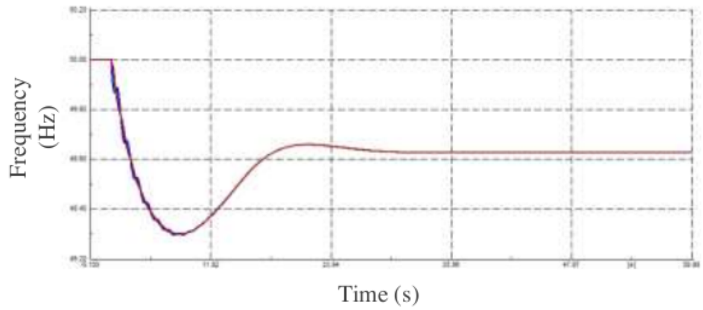

Figure 6. System's frequency performance if Jeneponto WPPs are out of the system at 150 kV buses

Figure 7 and figure 8 describe the frequency at all substations when the Sidrap WPPs and Jeneponto WPPs are suddenly disconnected from the system. The system undergone a frequency instability in form of frequency deviation which is an increase and decrease from its frequency value. Figure 7 shows the frequency deviation at the 275 kV substations. Some 150 kV substations on the system experienced a
decrease in frequency up to 48.2 Hz as informed in figure 8 Some of them experienced frequency fluctuations that would disrupt the stability of the system.

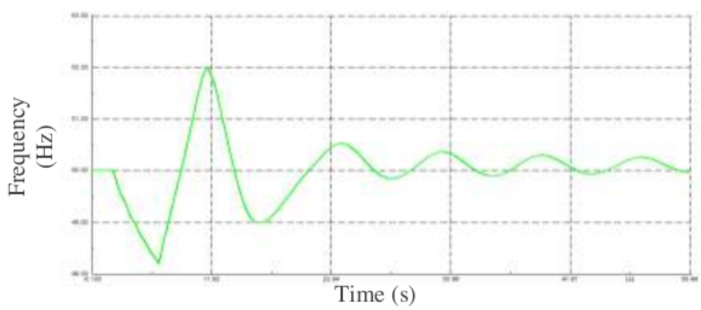

Figure 7. System's frequency performance if both Sidrap and Jeneponto WPPs are out of the system at 275 kV buses.

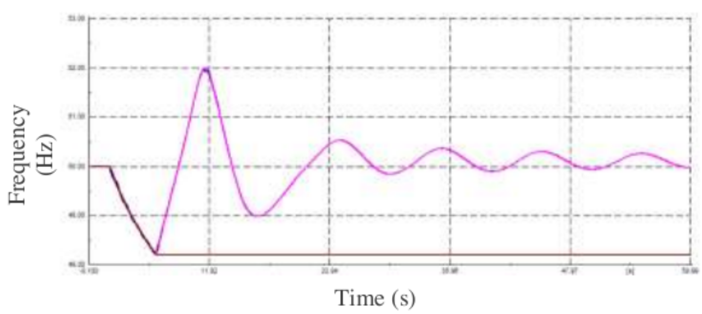

Figure 8. System's frequency performance if both Sidrap and Jeneponto WPPs are out of the system at 150 kV buses.

In this case, load shedding mechanism is needed in order to maintain the system's stability and to avoid the system from being collapse. The selected load shedding locations are based on the Southern Sulawesi's State Electricity Company. Figure 9 and figure 10 show the system's frequency at all buses after load shedding. If Sidrap WPPs and Jeneponto WPPs are suddenly loss from the system, then some load are disconnected from the system, the system can maintain its frequency stability. The initial frequency decreased by 49.18 Hz in seconds to 7.68 then rises towards a stable state of 49.73 Hz. Nevertheless, to avoid load shedding action, it would be beneficial for the utility to perform study on reactive power compensator [20] for Southern Sulawesi system after the integration of these WPPs, since WPPs are absorbing reactive power [21, 22]. In addition, optimal power flow study is also essential to identify any potential of transmission congestion [23, 24] as well as the system's reliability considering WPPs intermittency and low inertia characteristic [25].

4. Conclusions

This work evaluates the frequency stability of the Southern Sulawesi interconnected power system when Sidrap WPPs and/or Jeneponto WPPs are suddenly out of the system. When Sidrap WPPs or Jeneponto WPPs is suddenly disconnected from the system, the frequency at the Southern Sulawesi can return to its steady state value. However, when both Sidrap WPPs and Jeneponto WPPs are out of the system at the same time, the system frequency at some areas have deviation whereas frequency at some areas decrease to 48.2 Hz. Hence, in this case, load shedding is needed to restore the system frequency back to its operational limit. By performing load shedding at some buses, the system frequency can return to its stable limit.

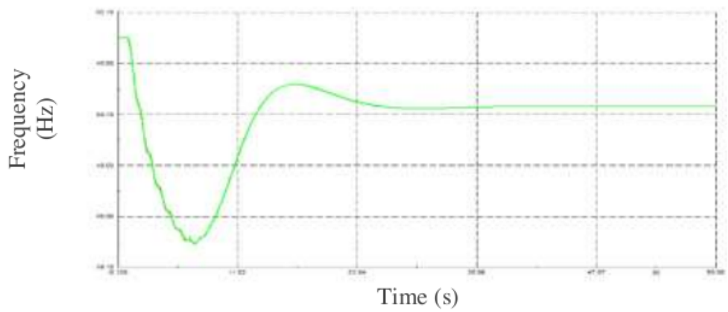

Figure 9. System's frequency performance if both Sidrap WPPs and Jeneponto WPPs are out of the system and with load shedding at 275 kV buses.

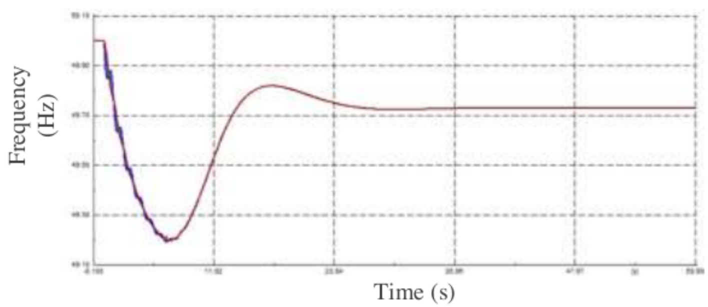

Figure 10. System's frequency performance if both Sidrap WPPs and Jeneponto WPPs are out of the system and with load shedding at 150 kV buses.

Acknowledgements

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