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by M. Bachtiar Nappu

Strategic Placement of Capacitor and DG for Voltage Improvement after Large Penetration of Renewable Energy Power Plant: An Indonesian Study

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***Abstract*— The integration of Poso hydro power plant into the Southern Sulawesi power systems in Indonesia brings some consequences for instance under-voltage condition. Therefore, the purpose of this study is to overcome such problems by determining appropriate size and location of both reactive power compensation and distributed generations. A load flow study is utilized before and after the integration to find out weakest buses in terms of unstable voltage. Then simulation to determine size and location for both DG and capacitor bank is examined. The results show that as the best combination strategy is achieved therefore some lower voltage buses improve to the stable level at the same time.**

***Keywords*— distributed generation; optimal power flow; voltage stability; capacitor bank; reactive power compensation.**

I. Introduction

Currently, the Southern Sulawesi power grid has an adequate electrical power reserves, making it in excellent circumstance to operate. Nevertheless, the system's stability is more likely to worsen once large power generation unit, loads and transmission lines are connected to the grid, including the needs of reactive power requirements. In addition, several nations around the world confronts with the problem of lacks electricity supply and superfluous consumption of fossil fuels [1]. This will eventually be able to change the stability based on the system's frequency parameter values and voltage levels at each interconnected bus [2-4]. Moreover, transmission congestion issues are more likely to happen following such condition [5-11].

The purpose of this study is to evaluate the voltage fluctuation before and after the Poso hydro power plant is integrated into the Southern Sulawesi power grid. Furthermore, the evaluation will be used as basis to decide the most optimal location and size of capacitor bank distributed, as reactive power compensation, as well as distributed generations (DGs) for improving voltage profile [12, 13]. In order to attain an optimum performance of a new development of power plant, a systematical and comprehensive investigation is required [14]. The main aspects to consider in this case are system stability such as voltage and frequency performance, security concern as well as its economic dispatch issue [15].

Therefore, this study utilizes Newton-based optimal power flow, where the results of the proposed method are then employed to examine best location and size for placement DG and capacitor banks as reactive power compensation devices [16, 17].

II. Optimal Power Flow, Reactive Power Compensation and Distributed Generation

A. *Optimal Power Flow Based on Newton's Method*

The optimal power flow is a very large and complex mathematical program [18, 19]. Optimal power flow can be described as the minimization of real power generation cost in an interconnected power system while real and reactive power, transformer taps and phase-shift angles are controllable and various inequality constraints are required [20]. Its procedure consists of methods of employing power flow techniques for the economic dispatch while definite controllable variables are adjusted to minimize the objective function such as the cost of active power generation or the power losses, while satisfying physical and operating limits on various controls, dependent variables and function of variables [21-23].

The objective function to be minimized in optimal power flow is the cost function

$$F = \sum_{i=1}^{NG} (a_i P_{Gi}^2 + b_i P_{Gi} + c_i) \qquad (1)$$

Subject to:

- Active power balance in the network

  $P_i(V,\delta) - P_{Gi} + P_{Di} = 0 \qquad (i = 1,2,\ldots NB)$

- Reactive power balance in the network

  $Q_i(V,\delta) - Q_{Gi} + Q_{Di} = 0 \qquad (i = NV+1, NV+2, \ldots NB)$

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Security related constraints:

- Limits on real power generation

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \qquad (i = 1,2,\ldots NG)$$

- Limits on voltage magnitudes

$$V_i^{min} \le V_i \le V_i^{max} \qquad (i = NV+1, NV+2, \ldots NB)$$

- Limits on voltage angles

$$\delta_i^{min} \le \delta_i \le \delta_i^{max} \qquad (i = 2,3, \ldots NB)$$

Functional constraint which is a function of control variables

- Limits on reactive power

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max} \qquad (i = 1,2,\ldots NG)$$

- Limits on active power flow of line and reactive power flow of line can be applied:
  - Real power flow equations are

$$P_i(V,\delta) = V_i \sum_{i=1}^{NB} V_j\{G_{ij}\cos(\delta_i - \delta_j) + B_{ij}\sin(\delta_i - \delta_j)\}$$

  - Reactive power flow equations are

$$Q_i(V,\delta) = V_i \sum_{i=1}^{NB} V_j\{G_{ij}\sin(\delta_i - \delta_j) - B_{ij}\cos(\delta_i - \delta_j)\}$$

B. Reactive Power Compensations

Reactive power compensating devices is utilized to improve power quality, stability and increase load power factor [24-30]. Both voltage regulation and reactive power need to be optimized so that transmission losses of the system can be reduced. Besides, it increases the level of bus voltage as well as controlling optimal compensation for reactive power shortage of the power system [31-34].

C. Distributed Generations

Electricity power generations with small size are generally named as distributed generation (DG). Integration of DGs into a power system has a high prominence because of their huge number of benefits and advantages [35, 36]. According to CIGRE, an International Council on Large Electricity Systems, power generation which comes up with capacity between 50 – 100 MW can be categorized as DG. The point of connection of such generation is mostly at distribution system [37-41]. Renewable energy based DGs are now becoming the main focus of many countries when analyzing their policy and planning trends specially as integrating them into a smart grid to perform a more sustainable electrical power system [42-46].

III. Results and Analysis

In this research, integration of a large hydro power plant to main power system network is analyzed. The influence of Poso hydro power plant interconnection into Southern Sulawesi power system grid is taken as a case study.

As can be seen from Fig. 1-3, the simulation result shows that before the integration, under-voltage condition happened in several unstable buses with magnitude voltage is below the stability limit or less than 0.9 p.u. as reference for standard voltage level. These week buses consist of Bus Tello Lama 70, Bus Bontoala, Bus Palopo, Bus LTuppa, Bus Poso Hydro Power, Bus Pomana and Bus Poso.

TABLE I. Fluctuation Of Unstable Bus With Under-Voltage

Bus Number	Bus Name	Voltage (p.u.)
11	Pangkep 150	0.924
13	Tonasa	0.946
14	Bosowa	0.919
15	Kima	0.924
16	Tello 150	0.928
17	Panakkukang	0.925
23	Barawaja	0.947
24	Tello lama 150	0.908
25	Tello lama 70	0.831
26	Bontoala	0.793
28	Tanjung bunga	0.948
40	LTuppa	0.881

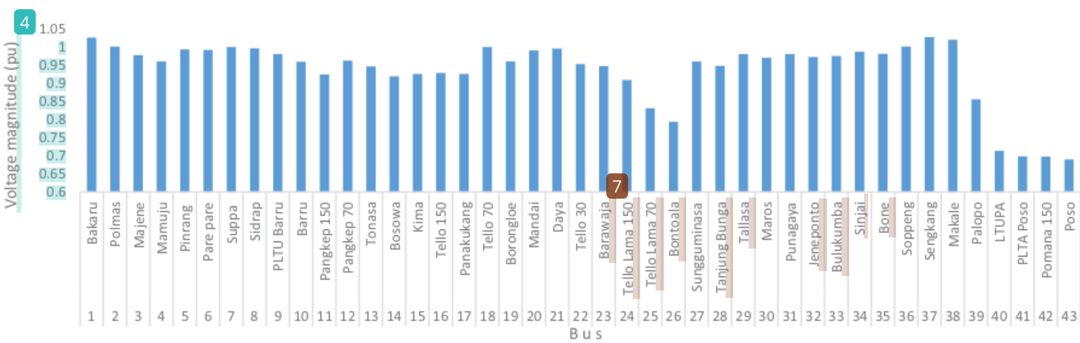

Fig. 1. Voltage profile of the Southern Sulawesi power system before the interconnection of Poso hydro power plant

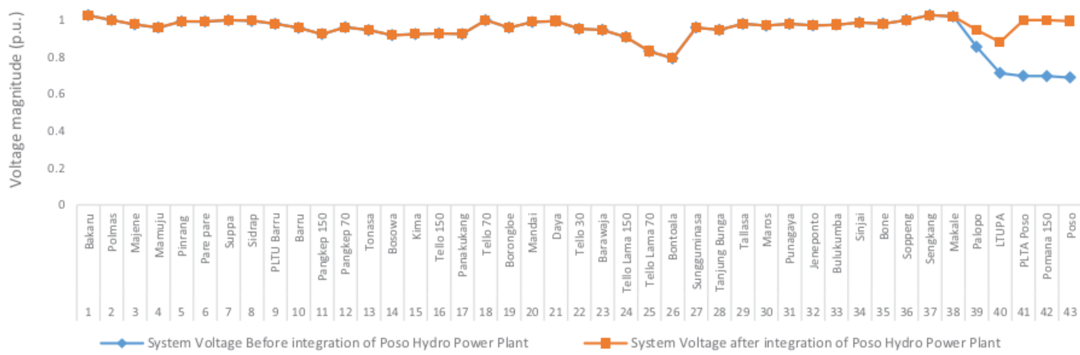

Fig. 2 Voltage profile of the Southern Sulawesi power system before and after the interconnection of Poso hydro power plant

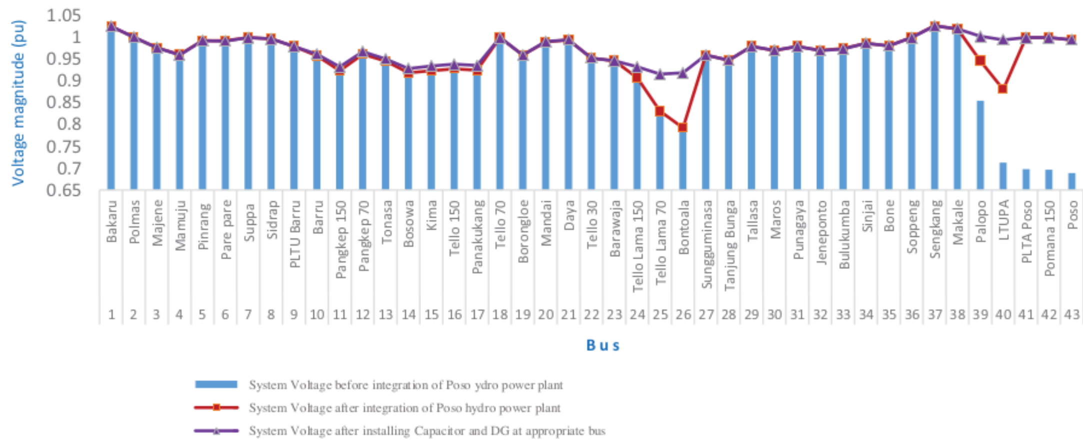

Fig. 3 Voltage profile comparison before and after the interconnection of Poso hydro power plant as well as after installing of Capacitor and DG

IV. CONCLUSIONS

The integration of Poso hydro power plant into Southern Sulawesi power grid brings some impacts, one of them is unstable bus voltages at several locations. The main cause of the unstable voltages is due to its geographic location in which the load centre of the system is situated in the southern part of the grid, whereas the Poso hydro power plant is placed at farther northern side of the power system. Furthermore, this is causing the allocation for reactive power is not optimal. As a result the voltage magnitude does not improve significantly as integration take place.

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