ICITACEE 2016

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Submission date: 27-Sep-2022 09:19AM (UTC-0400)
Submission ID: 1910355840
File name: nappu2016.pdf (317.93K)
Word count: 3443
Character count: 18024

Proc. of 2016 3rd Int. Conf. on Information Tech., Computer, and Electrical Engineering (ICITACEE), Oct 19-21st, 2016, Semarang, Indonesia

Network Losses Reduction Due To New Hydro Power Plant Integration

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Abstract—**This research aims to determine the location and capacity of distributed generations and reactive power compensations to minimize network losses of Southern Sulawesi power systems after the integration of Poso Hydroelectric Power Plants. The method used in this study is the Newton-Raphson power flow method, where the results of power flow are further employed to find the location and capacity of capacitors and distributed generations (DG). The proposed method is utilized to overcome the high network losses problems that emerged after the integration of Poso Hydro Power Plant. The replacement strategy of DG and reactive compensators are then examined particularly at unstable buses in diminishing the network losses.**

Keywords- network losses reduction, Newton-Raphson power flow, voltage profile improvement, voltage stability

I. INTRODUCTION

The integration of Poso Hydro Power Plant into the Southern Sulawesi network will be very helpful to the government in financial saving. The operation of Poso Hydro Power Plant will also reduce the electricity subsidies in the state budget for approximately Rp 2 trillion per year. The amount of the Rp 2 trillion savings come from the state budget that would have been spent to purchase fuel when generating electricity using diesel power plant. Water resources in Poso Lake are abundant as primary energy for Poso Hydro Power Plants, hence the government does not need to spend state budget on fuel subsidy. Poso Energy Hydro Power Plant consists of three projects where Poso-1 Plant has a potential capacity of 60 MW, Poso-2 Plant has a potential capacity of 180 MW and Poso-3 Plant has a capacity of 300 MW [1]. All of this three hydro power plants use the water resources in the Poso River, Sulewana Village, North Pamona, Poso, Central Sulawesi. Currently, Poso-2 Plant has already operating and provide electricity to the PLN from hydro energy [1].

At the present, Southern Sulawesi power systems are supplied from several power plants connected to the interconnection system of 275 kV, 150 kV, 70 kV and 30 kV. In addition, there are several small isolated systems in small islands such as Selayar Island, which is supplied from the local diesel power plants. The number of existing substations in Southern Sulawesi is 38 units with total capacity of 1,568 MVA. Power capacity of the existing generating plants is up to 1000 MVA whereas the peak load at night is able to reach 897.56 MVA. Therefore, currently, the Southern Sulawesi power system is in good condition as it has sufficient power reserves. However, the addition of generating units, loads and transmission lines will affect the system's stability. Not to mention, the possible transmission congestion problems that may occur because of these additions [2-17].

The aim of this study is to assess the dynamics of network losses before and after the integration of Poso Hydro Power Plant into the Southern Sulawesi power system and then to determine the most optimum location and size of distributed generations (DGs) and reactive power compensators to reduce network losses and improve voltage profile of the system. The development of new power plants require a systematical analysis to achieve optimal results. Security, economic and network losses aspects become the most important objects to be perceived. The addition of the new generating units, in this case Poso Hydro Power Plant will obviously affect the overall Southern Sulawesi power system, in voltage profile as well as network losses.

This research employs Newton-Rapshon power flow method [18, 19], where the results of Newton-Raphson power flow method are used to determine optimal location and capacity of reactive power compensation devices and distributed generation (DG) to address the problems that arise after the integration of Poso Hydro Power Plant, particularly the high network losses in some transmission lines.

This paper is organized as follow. Section II provides a brief overview on network losses, reactive power arrangement and distributed generations. Section III describes about research methodology. Section IV gives the results and analysis of this work and Section V concludes the main findings of the research.

II. NETWORK LOSSES, REACTIVE POWER ARRANGEMENT AND DISTRIBUTED GENERATIONS

By applying Kirchhoff, we obtain,

$$
\begin{aligned}
Ii &= y_{i0}V_i + y_{i1}(V_i - V_1) + y_{i2}(V_i - V_2) + \dots + y_{in}(V_i - V_n) \\
&= (y_{i0} + y_{i1} + y_{i2} + \dots + y_{in})V_i - y_{i1}V_1 - y_{i2}V_2 - \dots - y_{in}V_n \qquad (1)
\end{aligned}
$$

or

$$I_i = V_i \sum_{j=0}^{n} Y_{ij} - \sum_{j=1}^{n} Y_{ij} V_j \qquad j \neq i \qquad (2)$$

Active and reactive power at bus *i* are:

$$P_i + jQ_i = V_i I_i^* \qquad (3)$$

or

$$I_i = \frac{P_i + jQ_i}{V_i^*} \qquad (4)$$

By substituting I_i from Eq. 2, then,

$$\frac{P_i + jQ_i}{V_i^*} = V_i \sum_{j=0}^{n} Y_{ij} - \sum_{j=1}^{n} Y_{ij} V_j \qquad j \neq i \qquad (5)$$

The system's network losses can be written as,

$$\Delta Pt = P^2 \frac{R}{Vr^2} \text{Cos}^2\varphi \qquad (6)$$

There are several ways to reduce network losses, such as: increase the system's voltage level, reduce conductor's resistance or increase load power factor [20]. One way to improve the load power factor is by installing reactive power compensating devices. Reactive power and voltage settings is done by regulating the production and absorption of reactive power on each part of the power system. Several ways for reactive power and voltage settings are done by using the following ways, such as: installing static VAR compensator, shunt capacitor, Flexible AC Transmission System (FACTS); setting tap transformers; switching the transmission line; or setting the generator excitation [21]. The purpose reactive power and voltage regulation optimization are to increase the voltage profile, reduce active and reactive power losses and determine the optimal reactive power compensation for various operating conditions [22].

The term Distributed Generation (DG) is often used to represent a small-scale electricity generation. International Council on Large Electricity Systems (CIGRE) defines DG as each unit of power plant with maximum capacity of 50 MW to 100 MW, which is usually connected to the distribution network [23-28]. On the other side, the Institute of Electrical and Electronics Engineers (IEEE), defines DG as the generation of electrical energy by smaller equipment from main power generation facilities allowing the interconnection occurs at almost all nodes of the power system [29]. Meanwhile, the International Energy Agency (IEA), defines DG as electric power generating units on the side of consumers and supply power directly to the local distribution network [30].

III. RESEARCH METHODOLOGY

The step by step procedure of this research is as follow:

1. Calculate the power flow before and after the integration of Poso Hydro Power Plant with Newton-Raphson method to calculate bus voltage, power angle, active power, reactive power, and network losses in the transmission of the Southern Sulawesi power system.
2. Validate the results by comparing with data from the load dispatcher center (AP2B) of PLN.
3. Compare the voltage profile as well as network losses of the system before and after the integration of Poso Hydro Power Plant
4. Identify the unstable buses.
5. Once unstable buses are identified, then perform Newton-Raphson power flow to compute optimal capacity of DG and reactive power compensator until the system is stable.

IV. RESULTS AND ANALYSIS

A. Before the Integration of Poso Hydro Power Plant

The Southern Sulawesi power system is utilized as a case study to examine the impact of Poso hydro power plant penetration into the main grid. Table 1 shows the impedance data of the Sulselbar transimisson system. The initial data was taken at the peak load in at 11 March 2015, 7.30 pm. The Newton-Raphson power flow is then employed to see the initial condition of the power system using MATLAB software. Validation data showed that there are no significant differences between the results and data provided by the load dispatcher center.

Based on the power flow analysis results, before the integration of Poso Hydro Power Plant into the Southern Sulawesi network, there are 7 buses with voltage magnitude below the stability limit of 0,900 pu. These unstable buses include Bus 25, Bus 26, Bus 39, Bus 40, Bus 41, Bus 42 and Bus 43. In addition, there are 9 buses which fall into the critical category with voltage value between 0.90 pu to 0.95 pu, they are Bus 11, Bus 13, Bus 14, Bus 15, Bus 16, Bus 17, Bus 23, Bus 24 and Bus 28.

Total network losses for this condition is 44,534 MW and detail of losses for each line can be seen in Fig. 1 with the blue line.

B. After the Integration of Poso Hydro Power Plant

The voltage profile of the system after the integration of Poso Hydro Power Plant with capacity of 183.8 MW, has generally no significant changes. However, there are several buses which locate close to Poso Power Plant have voltage magnitude improvement. Nevertheless, after the Poso Hydro Power Plant penetration to the main grid, network losses increase from 44.534 MW to 48.438 MW, which means there is an increase of 3.904 MW of losses in the system. From Fig. 1, significant increase of network losses takes place in transmission lines between buses 27-29 of 6.52 MW and between buses 40-41 of 5.59 MW. In the system, Poso Hydro Power Plant is located farther northern side of the system whereas the main load is located in the southern part of the system. Therefore, even though with additional power generation, the network losses increase, instead of reducing.

From the simulation, it is obtained that the most optimal placement and capacity for DG to relieve some critical buses as shown in Table 2, is at Bus 26 and optimal placement and capacity for reactive power compensator is at Bus 40. With the addition of DG and reactive power compensator, the network losses decrease to 39.503 MW. There are losses reduction of 5.031 MW compare to the condition after Poso Hydro Power Plant integration. The green bar in Fig. 1 displays the network losses for every transmission line for the above condition.

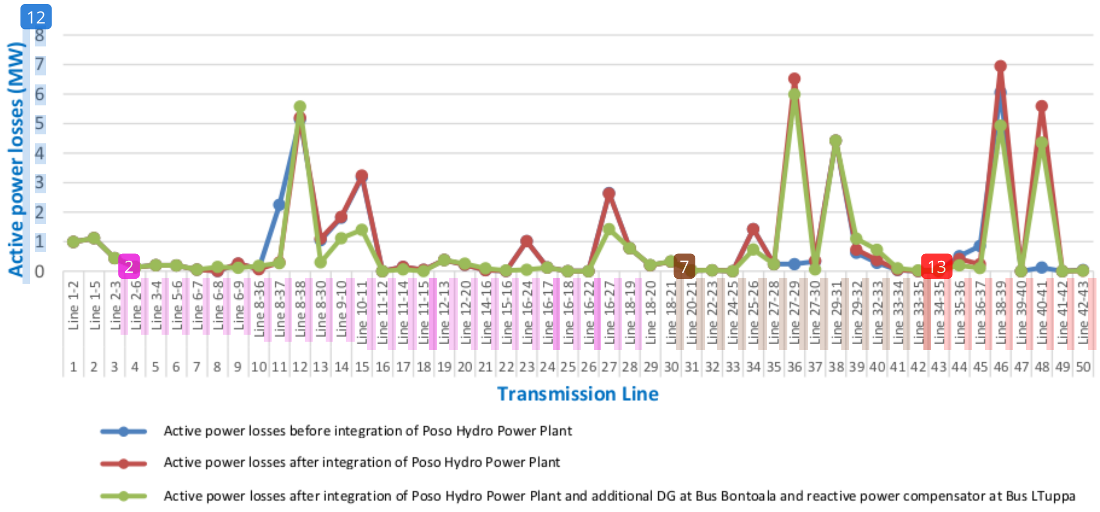

Fig. 1 Active power losses comparison at transmission lines before and after the integration of New Hydro Power Plant and addition of DG at Bus 26 and reactive power compensator at Bus 40

Tabel 1. Line Impedance of Sulselbar Network Power System.

LINE	**R**	**jx**	**y/2**
1-2	0,02627	0,09440	0,00743
2-3	0,05261	0,18902	0,00372
3-4	0,06553	0,20117	0,01012
1-5	0,03076	0,11023	0,01012
2-6	0,03663	0,13159	0,01819
5-6	0,01388	0,04974	0,00067
6-7	0,00787	0,02826	0,00056
6-8	0,02003	0,07198	0,00142
6-9	0,01173	0,03973	0,00198
9-10	0,01173	0,03973	0,00198
10-11	0,02419	0,08667	0,01167
11-12	0,00000	0,39492	0,00000
12-13	0,03275	0,06013	0,00005
12-20	0,36318	0,66671	0,0005
11-14	0,01090	0,03919	0,00493
11-15	0,02133	0,07223	0,0038
15-16	0,00960	0,03250	0,0038
14-16	0,01836	0,06215	0,00575
16-24	0,00726	0,02600	0,00088
16-17	0,00222	0,00700	0,00006
16-18	0,00000	0,41587	0,00000
16-22	0,00000	0,55350	0,00000
16-27	0,00385	0,02635	0,00124
22-23	0,12292	0,17508	0,00002
18-19	0,06069	0,11141	0,00034
18-20	0,05828	0,10699	0,00032
20-21	0,03420	0,06278	0,00019
18-21	0,02408	0,04421	0,00013
24-25	0,00000	0,41587	0,00000
25-26	0,04046	0,07428	0,00006
27-28	0,00707	0,04256	0,00136
27-29	0,00970	0,06649	0,00314
27-30	0,00613	0,05111	0,01756
29-31	0,00712	0,02380	0,00217
29-32	0,03241	0,13837	0,01973
32-33	0,04861	0,17466	0,00344
33-34	0,03120	0,11211	0,00882
34-35	0,04064	0,14603	0,01149
33-35	0,14390	0,51703	0,00882
35-36	0,04578	0,16306	0,00402
36-8	0,02855	0,09436	0,00482
36-37	0,02106	0,12670	0,00402
37-8	0,00613	0,05111	0,00342
8-38	0,06274	0,37753	0,01203
8-30	0,01235	0,08464	0,00399
38-39	0,03917	0,14076	0,00277
39-40	0,00000	0,17234	0,00000
40-41	0,01595	0,13289	0,00222
41-42	0,00000	0,01300	0,00000
42-43	0,04267	0,14446	0,00574

(Source: PT PLN (Persero) SULSELBAR)

Table 2 Buses with Critical Voltage after the Integration of Poso Hydro Power Plant

No.	Bus Number	Voltage (kV)
1	11	138.60
2	13	141.90
3	14	137.85
4	15	138.60
5	16	139.20
6	17	138.75
7	23	142.05
8	24	136.20
9	25	58.17
10	26	118.95
11	28	142.20
12	40	132.15

V. CONCLUSIONS

The addition of the new generating units, in this case Poso Hydro Power Plant obviously affect the overall Southern Sulawesi power system, both in voltage profile and network power losses as well. Therefore this study has assessed the dynamics of network losses before and after the integration of Poso Hydro Power Plant into the Southern Sulawesi power system and then to determine the most optimum location and size of distributed generations and reactive power compensators to reduce network losses and improve voltage profile of the system.

There is an increase of losses in the Southern Sulawesi power system after the integration of Poso Hydro Power Plant for 3,904 MW. The main cause for this losses increase is because the location of Poso Hydro Power Plant is located farther north of the Southern Sulawesi network configuration. Other factors that cause the high losses is the controlling reactive power supplies are located in the northern area and the main load demand in the region is at the southern part. Hence, the allocation of reactive power is not optimal and it does not influence significantly on the system. This causes the voltage magnitude values do not improve considerably after the Poso Hydro Power Plant integration.

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