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ANALYSIS OF POWER LOSSES DUE TO DISTRIBUTED GENERATION INCREASE ON DISTRIBUTION SYSTEM

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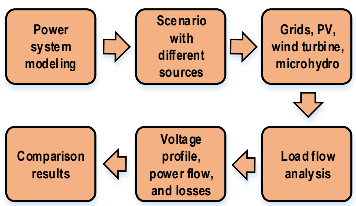
Graphical abstract



Abstract

Small-scale power plants injected into the existing distribution systems are commonly called as embedded or dispersed generation. The continuously increasing penetration of distributed generation becomes a challenge for conventional power systems. Recently developed distributed generation systems are mostly categorized into small scale plants in terms of power output. However, they are expected to be massive in terms of number. The power plants injection as well as their spread in the whole distribution systems will influence the power flow and losses in the network. Some researches have been undertaken recently to relate the embedded plants with the power losses and voltage profile of the networks. This paper presents a study on the influence of penetration level and concentration of distributed generation on power losses in the network. Steady-state power flow analysis is used to examine the power losses variation for a variety of distributed generation penetration. Based on the power flow analysis, voltage profile and power losses due to the power plants injection can be determined. The influence of various technologies used is also considered, including the use of wind power, photovoltaic and micro-hydro power plants. Four different scenarios to determine the effect of dispersed generation injection are proposed, starting from the original grid in the first scenario, being added with photovoltaic plant (0.5MVA) in the second scenario, the addition of wind power plant (0.5MVA) to the grid in the third scenario, and the fourth is the addition of microhydro power plant (1x2.5MVA) to the grid. The considered scenarios are based on the existing potential of the plants in the network system under concern, i.e. the Sengkaling Substation of the Pujon Feeder in Malang, Indonesia. Based on the analysis results, the injection of microhydro power plant (Scenario 4) presents the best influence being compared to the three other scenarios. The microhydro power potential is greater than that of the PV and wind power plants. Besides, it is well located in the middle of distribution system. From the point of view of power loss analysis, Scenario 4 also results in the smallest loss compared to the other scenarios. The least favorable losses reduction is given by Scenario 3 using the wind power plant injection, although the injection of renewable energy power plants in this study in general is proven to improve the voltage profile and reduction of power losses in the system.

Keywords: Distributed generation; distribution system; microhydro; photovoltaic; wind power

1.0 INTRODUCTION

About 80% of the world's energy needs up to now are still fulfilled using fossil fuels, while the use of renewable energy is still relatively small, covering hydropower (2.0%), biomass and waste energy (1.3%), and other renewable sources (6.6%) [1]. Indonesia as an archipelago is endowed with many potential sources of renewable energy, such as solar energy, wind, water, as well as ocean wave and tidal energy, to support sustainable development. On the other hand, the utilization of renewable energy in Indonesia is still relatively small, being amounted to about 17% of the total national electrical energy needs, with the largest contribution coming from hydroelectric plants (15%) and geothermal electricity (PLTP) (2%) [2].

Electric power system is currently evolving from a centralized system to a more dispersed one in the future. Previous structure of power utility, which is more centralized system, generally comprises many power stations connected directly to transmission networks, while nowadays in a decentralized system some smaller power generating units are connected directly to a distribution network, which is injected on the distribution system, which is located close to the customers. Many renewable energy generating units with small-scale capacities but large in number have been so far developed and are potential to be injected into the distribution system. Such plants are called embedded generation (EG) or distributed generation (DG) [3-4]. The addition of renewable energy sources is not only useful to achieve equitable access to energy but also of little impact on the environment.

The development towards the distributed systems is motivated by the increasingly rising awareness of environmental consideration, energy saving and sustainable development, which are relying on the diversification of energy sources in the long term and contributing greatly to the promotion of the use of renewable energy sources. The distributed generations (DG) coming from new and renewable energy sources can be built either individually or collectively or institutionally. Electricity market deregulation allows their injection to the existing electricity grid, which is generally a distribution network directly in contact with users.

The DG injection in the distribution system has been claimed to improve the power system distribution performances in term of the system quality, security, reliability, and efficiency [5-6]. Power injection of DG systems to existing power grids will affect the magnitude and direction of power flow in the network. In addition, the DG injection also could influence the voltage profile, power losses, fault level, power quality, stability, voltage regulators and protection coordination [5-13]. Therefore, technical and economical design and operation of the network need to be taken account by the utility companies.

The impact of distributed generation penetration into grids has become the object of lot of researches lately [4-13]. Many of the studies focused on specific cases (feeder and the connected distributed generation) or on the development of methodology for analyzing the condition of power losses in a case of distributed generation penetration. Not many of them discussed the variation of power losses along the feeder as a function of various parameters, for example, penetration level of distributed generation, combination of distributed generation technologies, location and distribution of the plants, as well as reactive power control strategy.

In this paper, an analysis on the distributed plants penetration is presented. The effect of penetration on power losses distribution is examined by considering some penetration cases with various penetration levels and plants concentrations. Power loss is evaluated based on the different load level with different DG injection. A variety of DG technologies, such as wind power, photovoltaic cells, as well as microhydro power plants, is considered in the simulation model. For each type of technology, various levels of penetration for a wide variety of installed plants, as well as various plants concentration possibilities in accordance with the number of distributed generation units connected along the feeder are taken into consideration.

2.0 METHOD

2.1 Approach taken

The voltage profile and power loss of the distribution network with different scenarios of the DG injection in the distribution system is examined using load-flow analysis by considering different load level and power production of the connected distributed plants. To analyze the overall impact, several cases are proposed by considering the combination possibilities of the distributed generation technologies used. The impact is measured from the difference between the power loss of the case taken and that in the base case without distributed generation. The comparison results are to be displayed in a graph form so that the change in the network power losses and also the voltage improvement as a function of concentration and penetration level of distributed generations can be examined for each technology used.

2.2 Computation Algorithms

To calculate the power loss, the power flow, and the voltage profile for each bus, the load-flow algorithm should be implemented with different load level under consideration. The Full Newton-Raphson (N-R) algorithm is used to perform the load-flow analysis such that all parameter above to evaluate the distribution system performance could be determined. The main advantage of the Newton Raphson method is its quadratic rate of convergence, which is faster than that of any other method. It is very reliable and least sensitive to factors causing poor convergence, such as choice of slack node or series capacitors. Both polar or rectangular formulation can be used, but in order to use the Newton method the equations must be separated into real and imaginary set.

The main disadvantage of the method is the necessity to formulate and invert the Jacobian matrix at each iteration. However, since the structure of the Jacobian matrix has identical sparsity content as the Y matrix, sparsity techniques can be used instead of inversions. This has the advantage of requiring only one ordering sequence and since the actual elimination and solution is relatively less time consuming, the method presents no problem in solution time or storage space.

The Radial Load Flow algorithm offers faster computation time than the N-R algorithm because it does not require the matrix inverse calculation at each step of iteration, although it is still to be done iteratively. This algorithm takes the advantages of radial or tree distribution networks. This advantage will be more pronounced if the size of the distribution network is bigger. However, its inherent drawback is that it only allows for the representation of PQ load nodes. Consequently, the possibility of reactive power control on the distributed generation system cannot be analyzed [4].

3.0 DATA AND MODELING

3.1 Network Modeling

The network model used to analyse the impact of distributed generations injection on the distribution network is a medium-voltage distribution network system of radial type. A case study of 20-KV distribution network system at the Substation Sengkaling Feeder Pujon in the city of Malang, East Java in Indonesia, has been considered. The main data of the distribution system include the feeder capacity of 30-MVA and the line length of ±98 kms. The total real power generation of the Pujon feeder system is 5.39-MW, whereas its total reactive power is 2.08-MVAR. The total real power load is 4.65-MW, whereas its total reactive power load is 1.53-MVAR.

3.2 Distributed Generations Modeling

The effects of distributed generation injection on the distribution system power loss greatly depend on the number and size of the distributed plant units as well as their energy production patterns. The distributed plants are characterized by their development technologies as well as their reactive power control scheme. The energy production per hour of each distributed generation unit over an entire year is modelled based on its particular technology characteristics.

A wind turbine is simulated using Markov matrix simulation method [4]. Correlation matrix is built using the actual production data per hour of the windfarm. A windfarm is simulated as a single unit of wind power plant with an installed capacity equal to the total capacity of the windfarm.

The PV system connected to the grid is different from other type of power plants. The most fundamental difference is the absence of mechanical devices used in the conversion process of solar energy. The PVDG can be modeled as controlled constant P and V (PV model) and controlled constant P and Q (PQ Model) [12]. The load on PVDG converter is power load on the grid (load feeders). The main prerequisite of PVDG connected to the grid is determined by the quality of the current and voltage output of the PV system with the quality of the current and voltage on the grid. The detailed block-diagrams of Model PQ and Model PV control are given in [13]. The PV and microhydro inpact on the distribution system interm of the power system stability has been discussed in the [11].

Indonesia is very rich in hydropower potential for electrical energy generation. The hydropower plants which are possible to be injected in a form of distributed generation units are those of potential up to 5-MVA [2]. The generation of base load is determined as a reference used to model the distributed generation units which can produce full power during almost the whole year long. The base load is only supplied by the grid system.

It is commonly considered that the distributed plants have no ability to control voltage, so that in the load flow analysis it is usually modeled as a negative load, i.e. as a PQ node. Nevertheless, if the distributed plant enables the reactive power control, the node to which it is connected should be modeled as a PV node. It implies that the generator of the distributed plant has the ability to maintain the reference value of the voltage as long as the reactive power given is within its maximum and minimum values limit.

3.3 Load Modeling

To calculate the energy losses per hour it is necessary to know in advance the energy consumption per hour at each load node. The used testing feeder is the Pujon feeder system with a maximum load of approximately 4.65MW. Load node is to be modeled as a constant power sink, which is not dependent on the magnitude of the feeder voltage.

3.4 Study Cases

Several cases are proposed to analyze the impact of the distributed generation penetration on the distribution network system of Substation Sengkaling Feeder Pujon of Malang area in East Java, Indonesia. Using the available potential, three distributed plants being considered for injection are microhydro, photovoltaic and wind power plants. The considered cases also take into account the possible combination of plants injection, as shown in Table 1.

Table 1 Cases of distributed generation plants injection
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Case	Grid	PV (0.5MVA)	Wind turbine (0.5MVA)	Microhydro (1x2.5MVA)
1	X			
2	X	X (Bus 17)		
3	X		X (Bus 98)	
4	X			X (Bus 78)
5	X	X (Bus 17)	X (Bus 98)	
6	X	X (Bus 17)		X (Bus 78)
7	X		X (Bus 98)	X (Bus 78)
8	X	X (Bus 17)	X (Bus 98)	X (Bus 78)

It shows eight cases based on a combination of the distributed plants injection, started with the use of just the original grid system, ended in Case 8 with the use of the whole three distributed generation plants in the injection process. The potential injection location of the photovoltaic power plant of 0.5MVA is on Bus 17, the wind power plant of 0.5MVA on Bus 98, and the microhydro power plant of 1x2.5MVA on Bus 78.

4.0 RESULTS AND DISCUSSION

4.1 Case 1: Grid System

Modelling has been performed using the PSAT simulation software based on the single-line diagram and the data of Sengkaling Substation Pujon Feeder. Load-flow analysis under steady-state condition has been done to simulate the condition before and after the injection of microhydro, PV and wind power plants.

Load flow simulation has been undertaken by defining one bus as slack-bus with voltage of 1.0 p.u., while setting all buses to which the distributed plants have been connected with the voltage value of 1.0 p.u. The simulation results of Case 1, where the only power supply is coming from the grid system through a 30-MVA transformer of 150kV/20kV, are given in Table 2.

Table 2 Generation, loading, and power losses of case 1

Global Summary Report	Real Power [MW]	Reactive Power [MVar]	% MW	% MVAR
Total Generation	4.69	1.68	100	100
Total Load	4.35	1.43	92.75	84.85
Total Losses	0.34	0.26	7.25	15.16

Based on the voltage profile obtained using load flow analysis, all buses have been experiencing a voltage drop to the value below 0.95 p.u. except on Bus 0, Bus 1, and Substation bus. The lowest voltage of 0.91 p.u. has been observed on Bus 117, which is the farthest bus along the Pujon feeder distribution network. This value is almost approaching the lowest allowable limit of voltage service standard, i.e. 0.9 p.u.

Load flow analysis also results in the total generation, load and power losses on the network, as shown in Table 2. The total power generation is 4.69 MW and 1.68 MVAR, with the total load of 4.35 MW and 1.43 MVAR. Meanwhile, the total power losses are equal to 0.34 MW (7.25%) and 0.26 MVAR (15.16%) of total generation. Referring to the prevailing standard, these active power losses are unacceptable, as it is required to be less than 3% of the total generation.

4.2 Case 2: Grid system + PV (0.5MVA)

Based on the voltage profile obtained using load flow analysis, the voltage on the Sengkaling substation main intake has been set to $1.0\angle 0°$ p.u. (Bus 0). A photovoltaic plant has been injected on the Bus 17 and the bus voltage has been set to 1.0. p.u. The consequence of this injection showed some voltage improvement on all buses, with respect to Case 1. All buses voltage has been improved to more than 0.95 p.u. with the minimum voltage was 0.98 p.u.

Load flow analysis also results in the total generation, load and power losses on the network, as shown in Table 3. The total power generation is 5.39 MW and 2.08 MVAR, with the total load of 4.65 MW and 1.53 MVAR. Meanwhile, the total power losses are equal to 0.75 MW (13.84%) and 0.56 MVAR (26.70%) of total generation. Referring to the prevailing standard, these active power losses are unacceptable, as it is required to be less than 3% of the total generation.

Table 3 Generation, loading, and power losses of case 2

Global Summary Report	Real Power [MW]	Reactive Power [MVar]	% MW	% MVAR
Total Generation	5.39	2.08	100	100
Total Load	4.65	1.53	86.16	73.29
Total Losses	0.75	0.56	13.84	26.70

4.3 Case 3: Grid system + Wind turbine (0.5MVA)

Based on the voltage profile obtained using load flow analysis, the voltage on the Sengkaling substation main intake has been set to $1.0\angle 0°$ p.u. (Bus 0). A wind power plant has been injected on the Bus 98 and the bus voltage has been set to 1.0. p.u. The consequence of this injection showed some voltage improvement on all buses, with respect to Case 1. All buses voltage has been improved to more than 0.95 p.u. with the minimum voltage was 0.98 p.u.

Load flow analysis also results in the total generation, load and power losses on the network, as shown in Table 4. The total power generation is 5.42 MW and 2.11 MVAR, with the total load of 4.65 MW and 1.53 MVAR. Meanwhile, the total power losses are equal to 0.77 MW (14.25%) and 0.56 MVAR (27.57%) of total generation. Referring to the prevailing standard, these active power losses are unacceptable, as it is required to be less than 3% of the total generation.

Table 4 Generation, loading, and power losses of case 3

Global Summary Report	Real Power [MW]	Reactive Power [MVar]	% MW	% MVAR
Total Generation	5.42	2.11	100	100
Total Load	4.65	1.53	85.75	72.43
Total Losses	0.77	0.58	14.25	27.57

4.4 Case 4: Grid system + Microhydro (1x2.5MVA)

Based on the voltage profile obtained using load flow analysis, the voltage on the Sengkaling substation main intake has been set to 1.0∠0° p.u. (Bus 0). A microhydro power plant has been injected on the Bus 78 and the bus voltage has been set to 1.0. p.u. The consequence of this injection showed some voltage improvement on all buses, with respect to Case 1. All buses voltage has been improved to more than 0.95 p.u. with the minimum voltage was 0.99 p.u.

Load flow analysis also results in the total generation, load and power losses on the network, as shown in Table 5. The total power generation is 4.82 MW and 1.66 MVAR, with the total load of 4.65 MW and 1.53 MVAR. Meanwhile, the total power losses are equal to 0.18 MW (3.69%) and 0.14 MVAR (8.22%) of total generation. Referring to the prevailing standard, these active power losses are unacceptable, as it is required to be less than 3% of the total generation.

4.5 Analysis Of All Cases

Steady-state study using load flow analysis on the four cases has been performed to obtain the voltage profile and power losses in the system. Summary of voltage profiles for each case is given in Table 6, while in a graph form is shown in Figure 1.

Table 5 Generation, loading, and power losses of case 4

Global Summary Report	Real Power [MW]	Reactive Power [MVar]	% MW	% MVAR
Total Generation	4.82	1.66	100	100
Total Load	4.65	1.53	96.31	91.78
Total Losses	0.18	0.14	3.69	8.22

For Case 1 with only power supply from the grid system, the 20kV system voltage profile experienced voltage drop to below 0.95 p.u. The line-end voltage of each case 1, 2, 3, and 4 are respectively 0.907 p.u., 0.977 p.u., 0.997 p.u. and 0.994 p.u. Case 1 gives the lowest voltage profile than the three other cases. Case 4 using the injection of microhydro power plant provides the best improvement with respect to the three other cases. It is related to the fact that the capacity of microhydro power plant under consideration is bigger than the other considered distributed plants, which are only 0.5MVA. Besides, its location was relatively in the middle of the system.

The summary of total generation, loading, and power losses of all cases of distributed plants injection is given in Table 7. Case 3 with the injection of wind power plnat of 0.5MVA results in the largest power losses, namely 14.25% of active power and 27.57% of reactive power with respect to total power generation. Injection of microhydro power plant brings the best improvement in terms of voltage profile and power losses reduction, namely 3.69% for active power and 8.22% for reactive power being referred to the total power generation in the distribution system of Sengkaling substation Pujon feeder.

Table 6 Voltage profile of all cases of distributed plants injection

Bus	Case 1	Case 2	Case 3	Case 4
Bus 0	1.000	1.000	1.000	1.000
Bus GI	1.000	1.001	1.000	1.000
Bus1	0.951	1.000	0.990	0.992
Bus9	0.933	0.999	0.986	0.989
Bus78	0.911	0.981	0.997	1.000
Bus17	0.929	1.000	0.986	0.989
Bus26	0.928	0.999	0.986	0.989
Bus42	0.917	0.987	0.990	0.993
Bus65	0.912	0.982	0.984	0.987
Bus78	0.911	0.981	0.997	1.000
Bus98	0.910	0.980	1.000	0.997
Bus117	0.907	0.977	0.997	0.994

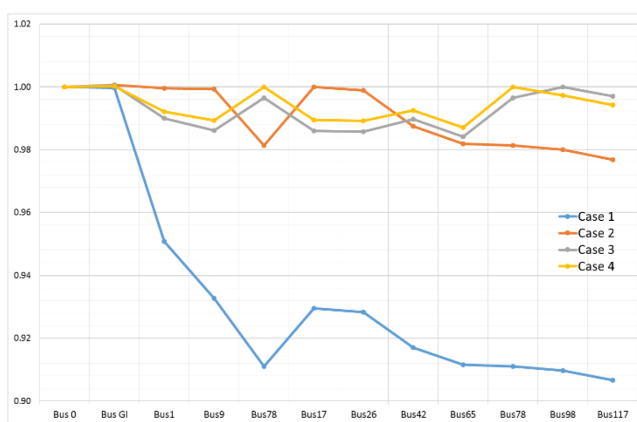

Figure 1 Voltage profile of all cases

Table 7 Generation, loading, and power losses of all cases of distributed plants injection

Case	Generation		Load		Losses		Percentage to losses (%)	
	P	Q	P	Q	P	Q	P	Q
	MW	MVAR	MW	MVAR	MW	MVAR	MW	MVAR
1	4.69	1.68	4.35	1.43	0.34	0.26	7.25	15.16
2	5.39	2.08	4.65	1.53	0.75	0.56	13.8	26.70
3	5.42	2.11	4.65	1.53	0.77	0.58	14.25	27.57
4	4.82	1.66	4.65	1.53	0.18	0.14	3.69	8.22

5.0 CONCLUSIONS

Some conclusions to be drawn from the simulation results and analyses of all proposed generation scenarios are as follow:

- Steady-state analysis has been performed using load-flow analysis to examine the voltage profile and power loss of the system.
- On the base scenario with supply only from grid system, the 20-kV system was experiencing voltage drop to below 0.95 p.u.
- The voltage profile improvement to the value above 0.95 p.u. has been obtained through the injection of distributed generations consisting of photovoltaic, wind turbine and microhydro power plants.
- Power losses analysis shows that the smallest power losses has been obtained from the injection of microhydro power plant (2.5MVA), while the largest losses has been given by the injection of wind power plant to the original grid system.
- Injection of wind generator, microhydro, and PV power plants in general improve the voltage profile and reduce the power losses in the system.

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