INTEGRATION OF DISTRIBUTED GENERATORS INTO POWER SYSTEM FOR LOSS MINIMIZATION AND VOLTAGE STABILITY

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ABSTRACT - This paper describe the integration of distributed generators (DG) into the power system to analyze the losses and voltage stability. The location of DG is based on the weakest bus determined heuristically with the objectives to minimize losses and to improve the voltage stability. The size of DG can be integrated at the weakest bus. Load flow analysis is used to simulate the power loss and voltage profile of the system. The proposed method was applied to a 6-bus and 14-bus IEEE system to show its capability and feasibility. All simulations were done using the MATLAB version 7.6 programming.

Keywords - Distributed generator, losses, voltage stability, load flow analysis.

1.0 INTRODUCTION

Distributed generation (DG) is an emerging concept in electricity market which represents good alternative for electricity supply instead of traditional central generation concept [1]. The planning of the system in presence of DG will require the assessment of several factors such as the number and the capacity of units, best possible location in the network, and the impact of DG on the system operation characteristics such as system losses, voltage profile, stability and reliability issues [2]. Most types of DG utilize traditional power generation paradigms such as diesel, combustion turbine, combined cycle turbine, and low-head hydro or other rotating machinery. But in addition, DG includes fuel cells and renewable power generation methods such as wind and solar [3].

The problems involving the integration of DG are not easy to deal with. Some contributions have been developed to solve parts of the problem [3]. When the DG were installed in distribution feeders and participated into system operation, the problems including changes of power flows, power quality, ferroresonance, voltage control, losses reduction, protection device coordination and voltage flicker etc., all need to be taken into account. Therefore, an efficient and robust power system load flow method taking the mathematical model of DG into account is the basic requirement for those analyses.

This project presents the integration of DG into power system to minimize the losses and to improve the voltage stability. Newton-Raphson power flow solution is used to determine the total minimum losses and voltage profile. The size and location will be determined using heuristic method.

2.0 THEORETICAL BACKGROUND

2.1 Power Flow Analysis

Power flow studies, commonly referred to as load flow, are the backbone of power system analysis and design. They are necessary for planning, operation, economic scheduling and exchange of power between utilities. In addition, power flow analysis is required for many other analyses such as transient stability and contingency studies.

The most common technique used for the iterative solution of nonlinear algebraic equations is Gauss-Seidel, Newton-Raphson, and Quasi-Newton methods. The Gauss-Seidel and Newton-Raphson methods are discussed for one-dimensional equation, and are then extended to *n*-dimensional equations.

In solving a power flow problem, the system is assumed to be operating under balanced conditions and a single-phase model is used. Four quantities are associated with each bus. These are voltage magnitude $|V|$, phase angle δ, real power P and reactive power Q.

Newton's method is mathematically superior to the Gauss-Seidel method is less prone to divergence with ill-conditioned problems. The Newton-Raphson method is found to be more efficient and practical. The number of iteration required to obtain a solution is independent of the system size, but more functional evaluations are required at iterations. The equation can be written in term of

$$Pi = \sum_{j=1}^{n} [Vi][Vj][Yij]\cos(\theta ij - \delta i + \delta j) \ldots\ldots\ldots (1)$$

$$Qi = -\sum_{j-1}^{n} [Vi][Vj][Yij]\sin(\theta ij - \delta i + \delta j) \ldots\ldots\ldots (2)$$

Equation (1) and (2) constitute a set of nonlinear algebraic equation in terms of the independent variables, voltage magnitude in per unit, and phase angle in radians [4].

2.2 Distributed Generators (DG)

Most of DG units generate electricity using alternative energy sources including windmills, photovoltaic (PV) modules, and fuel cells [5]. Therefore the high penetrations of DGs into the distribution systems can be significantly reduce the greenhouse gas emissions. Since most of DGs installed on the distribution system are close to the loads and are equipped with power-electronics interface, they can increase the power quality and reliability of distribution system through their fast dynamic responses to any change on the distribution system [6].

2.2.1 Simple Generator Model

A commonly used simplified 3rd-order linearized generator model is employed to build a prediction excitation model. With constant input mechanical torque, the generator can be modeled by the following equations [7][8]:

$$p\Delta w_r = \frac{-\Delta T_e - D\Delta w_r}{2H}$$

$$p\Delta\delta = w_0 \Delta w_r$$

$$p\Delta\varphi_{fd} = a_{32}\Delta\delta + a_{33}\Delta\varphi_{fd} + w_0\Delta u_{fd} \ldots\ldots\ldots (3)$$

$$\Delta T_e = k_2\Delta\delta + k_2\Delta\varphi_{fd}$$

$$\Delta V_t = k_3\Delta\delta + k_4\Delta\varphi_{fd} \ldots\ldots\ldots (4)$$

where $\Delta\delta$ is the incremental generator angle. $\Delta\omega_r$ is the incremental generator speed. ω_o is the synchronous speed. Δu_{fd} is the incremental excitation voltage; $\Delta\psi_{fd}$ is the incremental generator flux. ΔV_t is the incremental generator terminal voltage. ΔT_e is the incremental generator electric torque. The derivation and the notations of the above formulae can be found in [7].

The state equation of the DG-connected distribution system can be expressed as follows:

$$x(t) = A_c x(t) + B_c u(t)$$

$$\Delta y(t) = C_y x(t) \ldots\ldots\ldots (5)$$

$$where\ x(t) = [\Delta w_r(t)\ \ \Delta\delta(t)\ \ \Delta\varphi_{fd}(t)]^T$$

$$u(t) = \Delta u_{fd}(t)\ \ \Delta y(t) = [\Delta w_r(t)\ \ \Delta V_t(t)\ \ \Delta T_e(t)]^T$$

$$A_c = \begin{bmatrix} -\frac{D}{2H} & -\frac{k_1}{2H} & -\frac{k_2}{2H} \\ w_0 & 0 & 0 \\ 0 & a_{32} & a_{33} \end{bmatrix} \quad B_c = \begin{bmatrix} 0 \\ 0 \\ w_0 \end{bmatrix} \quad C_y = \begin{bmatrix} 1 & 0 & 0 \\ 0 & k_3 & k_4 \\ 0 & k_1 & k_2 \end{bmatrix}$$

2.2.2 Integration of DG in Distribution Network

DG can be grid independent or can be connected in parallel with the distribution network, or a combination of both (Figure 2.1) [9]. In case of parallel connection, both the DG and distribution grid are connected to the load. In an event of a grid failure the DG unit is disconnected from the grid and can continue to operate independently from the grid and thus create an “island” (island mode operation) [9].This means DGs act as backups for grid failure, this ensures that the power delivery to the load remains in a continuous state [10].

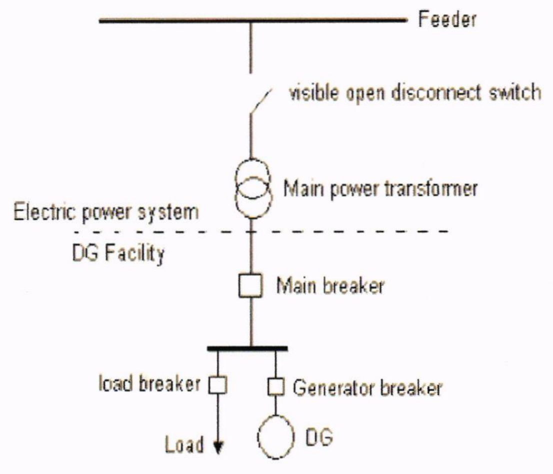

Fig.2.1: One-line diagram of the typical interconnection arrangement [9]

The DG connection and disconnection to the MV network is made by the circuit breaker at the generator side of the main power transformer (main breaker). Depending on the size of the plant the disconnect switch on the grid side of the transformer may be replaced by a circuit breaker. Other DG technologies apply slightly different interconnection arrangements. In all cases the voltage level at the interconnection point determines the need for a transformer. Smaller units can be directly connected to the low voltage network [10].

3.0 METHODOLOGY

The aimed of the study is to identify the effect of DG on the total losses and voltage profile in the power system. In order to integrate the DG at the weakest bus, the simulation of load flow analysis is used. The flowchart for the integration of DG is shown in Figure 3.1.

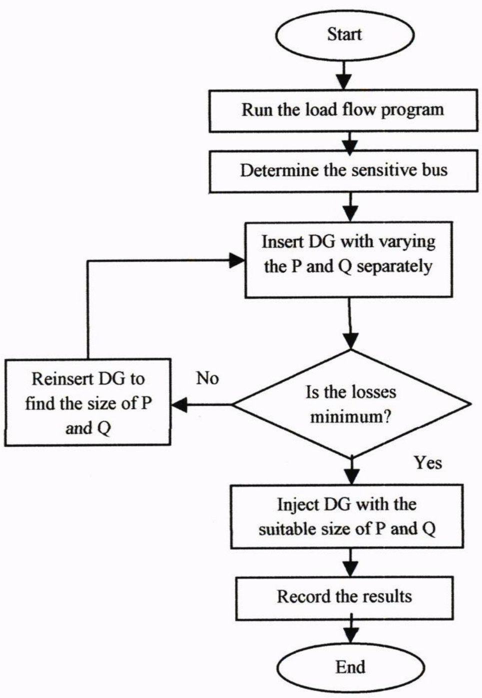

Figure 3.1: Flowchart of the integration of DG for loss minimization

The methods for loss minimization are implemented as below.

1. Run the load flow program using Newton-Raphson method.
2. Determine the sensitive bus using heuristic method.
3. Integrate DG by vary the real and reactive power separately.
4. Check if the total loss is minimized.
5. Repeat step (3) and reinsert the real and reactive power to find the suitable size of DG.
6. Integrate the size of DG that minimized the total losses and record the result.

To improve the voltage stability, DG is integrated to the weakest bus. The flowchart for improving the voltage stability is shown in Figure 3.2.

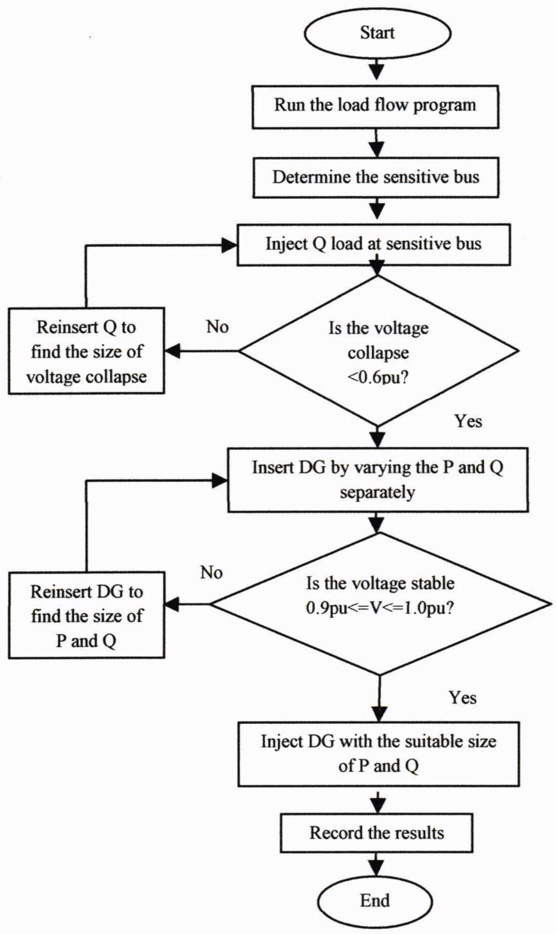

Figure 3.2: Flowchart of the integration of DG for voltage stability

The methods for the improvement of voltage stability are implemented as below.

1. Run the load flow program using Newton-Raphson method.

2. Determine the sensitive bus using heuristic method.
3. Inject the reactive power at the sensitive bus so that the voltages collapse.
4. Reinjection the reactive power until the voltage is below 0.6pu.
5. Integrate DG by vary the real and reactive power separately at the sensitive bus.
6. Check if the voltage is improved or stable.
7. Repeat step (5) and reinsert the real and reactive power to find the suitable size of DG.
8. Integrate the size of DG that improved the voltage profile until the system is stable.
9. Record the result.

4.0 RESULTS AND DISCUSSION

A test was conducted on the 6-bus and 14-bus IEEE reliability test system. The 6-bus system consists of 1 slack bus, 1 PV bus (generator bus) and 4 PQ bus (load bus) with 7 interconnection lines. The 14-bus system consists of 1 slack bus, 4 PV bus (generator bus) and 9 PQ bus (load bus) with 20 interconnection lines.

4.1 System Performance without DG

Table 4.1 shows the simulation result of the load flow program without injection of DG into the IEEE test system. The total losses are computed.

Table 4.1 Result for total losses without injection of DG into IEEE system

	Total Losses	
IEEE System	P(MW)	Q(MVar)
6-bus	5.222	22.124
14-bus	19.058	53.774

4.2 Location of Sensitive Bus

By using the heuristic method, the sensitive bus is determined. Figure 4.1 indicate that bus 5 shows the steepest slope and considered as the most sensitive bus in the 6-bus IEEE system. Bus 5 is chosen for the analysis.

For the 14-bus IEEE system, the similar method was conducted. The steepest slopes which indicate the most sensitive bus is bus 12 and it is chosen for the analysis.

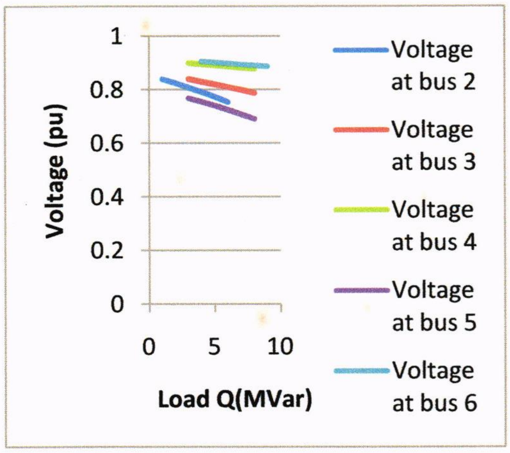

Fig.4.1: Voltage profile (pu) versus injected Q(MVar) at load for each bus at 6-bus system

4.3 System Performance with DG

4.3.1 Loss Minimization

Figure 4.2 and 4.3 shows that the integration of DG for the real and reactive power to minimize the losses for both system. For the 6-bus system, the size of DG for P is 23MW and Q is 16MVar. The power reduced to 2.793MW after integration.

For the 14-bus system, the size of DG for P and Q is 48MW and 14MVar. The system power loss reduced to 14.935MW after integration of DG. The results are tabulated in Table 4.2.

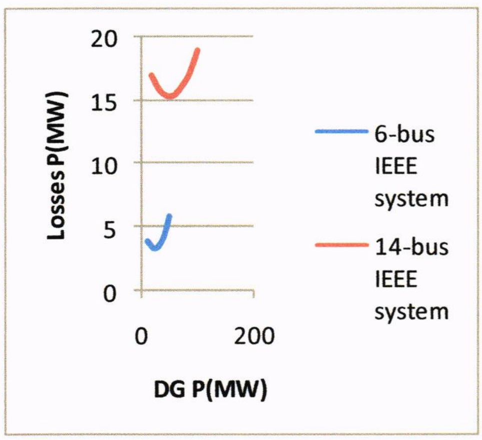

Fig.4.2: Power losses (MW) versus integration of DG for P(MW) into the system

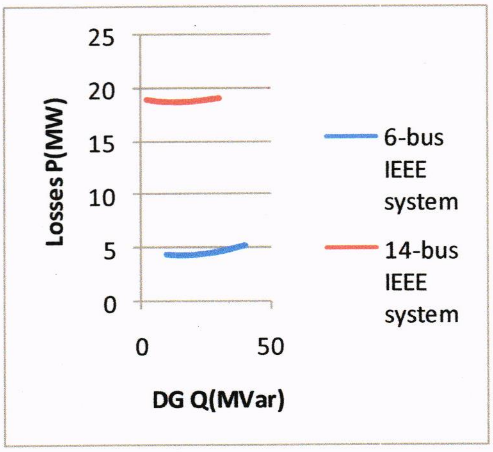

Fig.4.3: Power losses (MW) versus integration of DG for Q(MVar) into the system

Table 4.2: The size of DG for loss minimization into IEEE system

IEEE System	DG		Total Losses		% Reduction
	P	Q	P	Q	P
6-bus	23	16	2.793	12.070	46.5
14-bus	48	14	14.935	24.833	21.6

4.3.2 Improved Voltage Stability

The reactive load is first injected to the weakest bus to give unstable voltage condition. Table 4.3 shows the maximum loadability for 6-bus and 14-bus system. The voltage collapse for 6-bus system is 13.1MVar and 42MVar for 14-bus system. Figure 4.4 and 4.5 illustrate the size of DG for P and Q for each system. For 6-bus system, the size of P is 27MW with voltage 0.714pu and Q is 34MVar with voltage 0.996pu. P and Q for 14-bus system are 59MW and 71MVar with voltage 0.702pu for P and 0.998pu for Q with maximum loadability of 13.1MVar for 6-bus system and 42MVar for 14-bus system. The suitable size of DG for both P and Q were integrated to the weakest bus to improve the voltage close to 1.0pu. The size of DG is 27MW and 26MVar with bus voltage of to 0.998pu for 6-bus system and 59MW and 49MVar with bus voltage 1.0pu for 14-bus system. The result shows in Table 4.4.

Table 4.3: The maximum loadability for IEEE system

IEEE System	Load bus Q(MVar)	Voltage (pu)
6-bus	13.1	0.521
14-bus	42	0.508

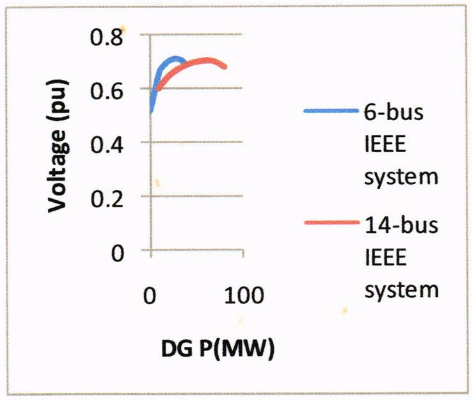

Fig.4.4: Voltage profile (pu) versus integration of DG for P(MW) into the system

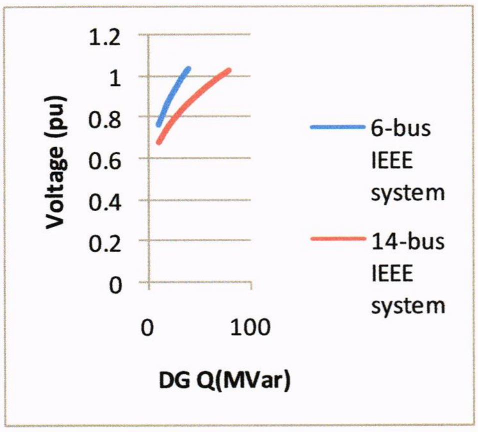

Fig.4.5: Voltage profile (pu) versus integration of DG for Q(MVar) into the system

Table 4.4: The size of DG for voltage stability into IEEE system

IEEE System	DG		Voltage (pu)
	P(MW)	Q(MVar)	
6-bus	27	26	0.998
14-bus	59	49	1.000

4.3.3 Loss Minimization and Voltage Stability

The next step is to minimize losses in the system and stabilize voltage. Table 4.5 shows that the size of DG for loss minimization and voltage stability for both systems. For 6-bus system, the power loss reduced to 2.782MW with voltage stability 0.998pu. For the 14-bus system, the power loss reduced to 15.075MW with voltage stability 1.0pu. All size of DG shows in table below.

Table 4.5: The size of DG for loss minimization and voltage stability at IEEE system

IEEE System	DG		Losses		Voltage (pu)
	P	Q	P	Q	
6-bus	27	26	2.782	12.076	0.998
14-bus	59	49	15.075	22.861	1.000

5.0 CONCLUSION

An investigation on the integration of DG was carried for loss minimization and improved voltage stability. For 6-bus IEEE system, minimum losses obtained when 23MW and 16MVar size of DG is incorporated at bus 5. The power loss reduction is 46.5%. For the 14-bus IEEE system, minimum losses are determined when 48MW and 14MVar size of DG is incorporated at bus 12. The power loss reduction is 21.6%. To obtain minimum losses and voltage stability, DG of 27MW and 26MVar is incorporated at bus 5 for 6-bus IEEE system with bus voltage 0.998pu. For 14-bus IEEE system, DG of 59MW and 46MVar is incorporated with bus voltage 1.0pu. DG is proven method to reduced the loss minimization and maintain the voltage stability.

6.0 FUTURE DEVELOPMENT

For future development, Artificial Intelligent such as Genetic Algorithm (GA) could be used to determine the size and location of distributed generators for loss minimization and voltage stability in power system.

7.0 ACKNOWLEDGEMENTS

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