Embedded Power Generation Studies in a Large Scale Local Power System

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Abstract - **Connection and use of embedded generators in distribution networks have been increasing in many parts of the world in recent years. Generally, this project is focused on embedded generation studies and the impact on the distribution system. These embedded generators, can significantly affect the power flow of the distribution network, the losses of such networks will in turn be affected as well. Since the embedded generation (EG) affects the load flows in the network. It is important to analyze and perform system studies to make sure whether the network is needed to adjust to accommodate the embedded generator. Thus, the power flow analysis is required to review all the impact of EG on the quality of power of the system. In this paper, A Matlab load flow analysis program with graphical user interface (GUI) has been developed by using Newton-Raphson method. As a result, the analysis between the network using EG and the conventional of power system connection can be made to look out the impact of both network on the power flow of the system. Therefore at the end of this project, the effect of EG on distribution system can be obtained and proved.**

Index Terms—**Embedded generation, Power Flow Analysis.**

I. Introduction

Today, environmental issues and concerns have increasingly come to the forefront. One topic that attracts greatest environmental concern is energy use. When we talk about the energy use, it must be related with the electrical power systems. Modern electrical powers systems have been developed mainly consist of four major parts which is generation, transmission and sub-transmission, the distribution system and loads of power systems which are divided into industrial, commercial, and residential. The basic operation of the electrical powers system are the large central generators feed electrical power up through generator transformers to high voltage interconnected transmission network. From transmission network, the power passed down through a series of distribution transformers to final circuits for delivery to the consumers.

However, recently there has been a considerable revival in interest in connecting generation to the distribution network and this has come to be known as embedded generation. The term ‘embedded generation’ comes from the concept of generation embedded in distribution network [1].

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Normally, the role of the distribution system is mainly confined to the interconnection between generator and the transmission system on one side and load centres on the other side. Hence, this network describe as passive networks. However, the integration of the embedded generation into distribution networks in recent years has transformed them from being passive to active networks with power flows and voltages determined by the generation as well as the loads. Embedded Generation therefore could effect on the distribution networks. As example, embedded generation change the power flows in the network and so will change the network losses. If a small embedded generation is located close to a large load the network losses will be reduced as both real and reactive power can be supplied to the load from the nearest generator [2].

But, if a large embedded generator is located far away from the loads then it is increasing the losses on the distribution system. Since the embedded generation affects the load flows in the network. It is important to analyze and performe system studies to make sure whether the network need adjustment to accommodate the embedded generator.

II. Literature Review

Effects of EG

Connecting a generation scheme to a distribution network will affect the operation and performance of the network depending on the scheme and rating of the generator itself [3]. The impacts are follows:

Power Flows

The significant penetration of embedded generation reverses the power flow and the network is no longer a passive circuit supplying loads. It becomes an active system with power flows and voltages determined by the generation as well as the loads [4]. In these cases, the generator exports excessive power to all the loads on the system to which it is connected. The surplus power is transferred into a higher voltage system.

Network Losses

EG will have an impact on losses in a network. The strategic placement of EG on the network can reduce losses normally seen by the system while improper placement may actually increase the network losses [5]. Allocation of EGs to minimize losses is like putting capacitor banks for loss reduction. The only difference is that EG will impact both real and reactive power flow, whereas capacitors only impact the reactive power flow. A small penetration of a strategically placed EG with an output of just 10-20% of the feeder demand can have a significant loss reduction benefit for the system [6].

Figure 1 shows a simple distribution network consisting of a radial feeder which has two loads (D1 and D2 at point A and B respectively) and a generator (G) embedded at point C. The power demanded by the loads is supposed to be constant and equal to 200 kW. The power delivered by the generator is 400 kW. The distance between A and B is the same as the distance between B and C. In addition, the distance between T and A is twice the distance between A and B. Moreover, assume the capacity of each of the sections is equal to 1000 kW. Impedances for sections AB and BC are assumed equal as are the distances. The impedance on TA is assumed twice that of AB and BC as the distance is double. Assume that constant voltages and those losses have a negligible effect on flows.

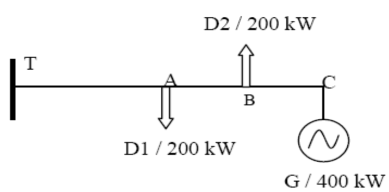

Figure 1: A simple distribution network

From the hypothesis made it is easy to demonstrate that the line looses (l) can be calculated multiplying the value of line resistance (proxy for impedance) (r) by the square of the active power flow (p) through the line:

$$l = rp^2 \qquad (1)$$

If embedded generator G is not present in the network (disconnected in Figure 2), then the loads must be served from point T with the resulting power flows, assuming no losses for the ease of illustration, of Figure 2.

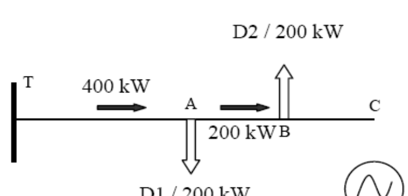

Figure 2: Power flow without EG

Losses in the network above are:

$l = 4^2 x(2x0.001) + 2^2 x0.001 = 0.036$ *p.u.* , or 3.6 kW.

Additionally, the usage of the network is such that the section TA is used to 40 percent of its capacity (400kW/1000kW) and section AB is used to 20 percent of its capacity (200kW/1000kW).

Now, assume embedded generation G is connected at point C as shown in Figure 3. The resulting power flows, assuming no losses again for ease of illustration, are the following:

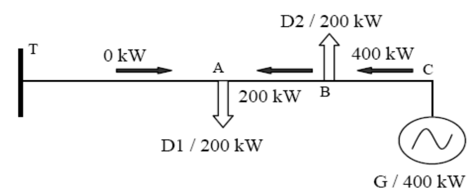

Figure 3: Power flows and usage with G producing 400 KW

The losses are:

$l = 0.001[2^2 + 4^2] = 0.02$ *p.u.* , or 2 kW,

which is a 44 % reduction in losses in the case without DG. The reduction from losses comes from transferring flows from the longer circuit TA to a shorter circuit BC. Moreover, since less power must travel over the transmission network to serves the loads D1 and D2, losses on the transmission system are reduced, or else equal.

III. POWER FLOW ANALYSIS

The power flow study also known as load-flow study is an important tool involving numerical analysis applied to a power system. Unlike traditional circuit analysis, a power flow study usually uses simplified notation such as a one-line diagram and per-unit system, and focuses on various forms of AC power (ie: reactive, real, and apparent) rather than voltage and current. It analyses the power systems in normal steady-state operation. There exist a number of software implementations of power flow studies. The most importance of power flow or load-flow studies is in the planning the future expansion of power systems as well as in determining the best operation of existing systems. The principal information obtained from the power flow study is the magnitude and phase angle of the voltage at each bus and the real and reactive power flowing in each line.The goal of a power flow study is to obtain complete voltage angle and magnitude information for each bus in a power system for specified load and generator real power and voltage conditions [2]. Once this information is known, real and reactive power flow on each branch as well as generator reactive power output can be analytically determined. Due to the nonlinear nature of this problem, numerical methods are employed to obtain a solution that is within an acceptable tolerance. The solution to the power flow problem begins with identifying the known and unknown variables in the system. The known and unknown variables are dependent on the type of bus. A bus without any generators connected to it is called a Load Bus. With one exception, a bus with at least one generator connected to it is called a Generator Bus. The exception is one arbitrarily-selected bus that has a generator. This bus is referred to as the Slack Bus.

A. Embedded Generation (EG)

Recently there has been a considerable revival in interest in connecting generation to the distribution network and this has come to be known as embedded generation. The term ‘embedded generation’ comes from the concept of generation embedded in distribution network [3]. Embedded generation is new way to save the cost of the generation cost and in the meanwhile reducing the total losses in distribution system. EG is very popular in Europe region where usually the renewable energy is used as the source of the generation such as wind, combine heat and power and solar. The total generation output of the EG is small and is below 20 MW and this generator is placed in the big building such as hospital, hotel, flat, shopping mall and others.

Normally, the role of the distribution system is mainly confined to the interconnection between generator and the transmission system on one side and load centers on the other side. EG have an impact on losses in a network. The strategic placement of EG on the network can reduce losses normally seen by the system while improper placement may actually increase the network losses [4]. Placing of EGs to minimize losses is like placing the capacitor banks for loss reduction. The only difference is that EG will impact both real and reactive power flow, whereas capacitors only impact the reactive power flow. A small penetration of a strategically placed EG with an output of just 10-20% of the feeder demand can have a significant loss reduction benefit for the system.

B. Relation Between Economic and the Embedded Generation

By generating power locally, embedded generation changes the flows and voltages in distribution system and affects the reliability profile of the network. Consequently, EG has an impact on the demand for distribution and transmission and the most important is it changes system operating costs and influences the value of the services delivered.

The principles of distribution system operation and development, in terms of the network operational practices such as protection, voltage control as well as system development and pricing policies are very much inherited from the period of passive distribution network and supply business. The restructuring of the industry and potential large scale penetration of embedded generation into these networks is now challenging the traditional views on the relationship between security economies of the supply. This indicated that there is a need, not only to reassess the suitability of the planning and pricing practices but also to investigate alternative approaches to these important issues.

IV. METHODOLOGY

NEWTON-RAPHSON METHOD

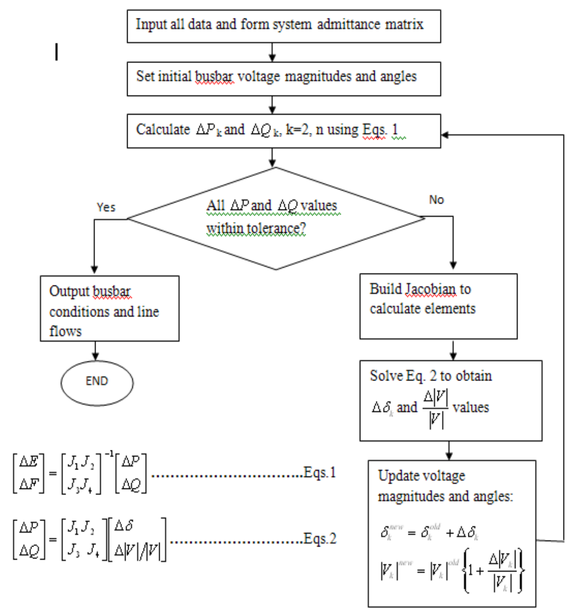

Figure 4: Flow chart for Newton Raphson Load Flow analysis

V. DATA FOR TEST SYSTEM-IEEE 14 BUS TEST SYSTEM

The IEEE 14 Bus Test system shown is a standard model published by IEEE. This study is done using this system as its test system in order to estimate the total losses of the system.

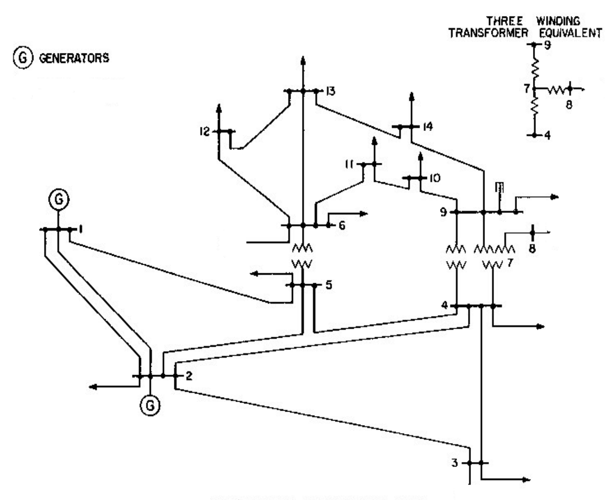

Figure 5: The single diagram of IEEE 14-bus system

The project is starting with determining the load flow analysis by using MATLAB (Newton-Raphson Method). For load data and line data, the data from IEEE are used for this study. From the bus data and line data, the total losses of the system can be determined. To investigate the impact of EG on losses of distribution networks, the two cases have been applied. First, the different location of EG which connected to bus and second, the different of the value of real power supply by EG. Then, let consider the first case where the embedded generation produces 5 MW connected to bus no. 3 shown as in figure 2. Then, the data in load data must be change at MW Generator value. New total losses of the system with embedded generation will evaluate. Each bus is categorized into one of the following bus types:

Swing bus, 1 -There is only one swing bus which for convenience is normally numbered as bus 1, and is a reference bus for which V_1 and d_1 are 1 and 0^o respectively.
Load Bus or **PQ bus, 0-** Most buses in a typical load flow program are load buses. P_k and Q_k are specified and the program computes V_k and d_k.
Voltage Controlled bus or PV bus, 2- These are generally generator buses where P_k and V_k are specified and Q_k and d_k are computed.

For this system, bus 1 is assumed to be the swing bus and bus 2 is the PV bus. The bus code need to change at load data from 0 to 2, which means the bus 3 has become from load bus to the voltage control bus. This step will repeated for the other buses with different value of power (MW) produces by EG such as 5 MW, 10 MW, 15 MW and 20 MW.

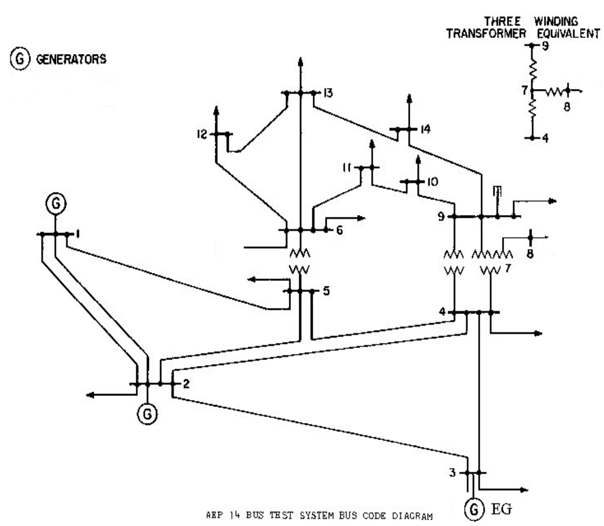

Figure 6: The single diagram of IEEE 14-bus system with embedded generation at bus 3.

IV. RESULTS

The results obtained after simulations of the power system model are presented in both tabular and graphical form. Tabular form of both voltage magnitude and phase angles are given in Table 1 while Figure 7 shows the corresponding voltage magnitude profiles graphically. In this case, the Power Flow Solution by Newton-Raphson Method has a maximum power mismatch of about 9.14498e-005 and converged after seven (7) numbers of iterations. The total active and reactive power losses in the system during this particular scenario were 515.508 MW and 13.338 MVar respectively.

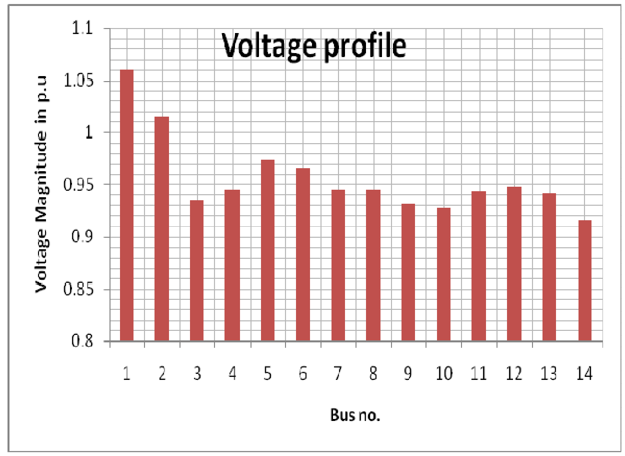

Figure 7: Voltage Profile

TABLE 1: BUS VOLTAGE OF THE 14-BUS SYSTEM

Bus no.	Total losses (MW)				
	Without EG	With EG			
		5	10	15	20
3	15.508	13.658	12.988	12.348	11.752
4		13.268	12.727	12.204	11.698
5		13.534	13.096	12.673	12.264
6		14.252	13.765	13.090	12.674
7		13.212	12.678	12.162	11.666
8		13.779	12.997	12.470	11.911
9		***13.188***	***12.657***	***12.147***	***11.604***
10		13.499	12.946	12.428	11.944
11		14.177	13.381	12.899	12.463
12		14.527	13.968	13.490	13.089
13		14.115	13.538	12.756	12.279
14		13.937	13.266	12.665	11.895

Bus no.	Voltage Magnitude	Angle Degree	Load		Generation		Injected
			MW	MVar	MW	MVar	MVar
1	1.060	0.000	0.000	0.000	234.496	51.275	0.000
2	1.015	-4.682	21.700	12.700	40.000	39.318	0.000
3	0.935	-12.741	94.200	19.000	0.000	0.000	0.000
4	0.945	-9.991	47.800	0.000	0.000	0.000	0.000
5	0.973	-8.452	7.600	1.600	0.000	0.000	0.000
6	0.966	-14.963	11.200	7.500	0.000	0.000	0.000
7	0.945	-13.558	0.000	0.000	0.000	0.000	0.000
8	0.945	-13.558	0.000	0.000	0.000	0.000	0.000
9	0.931	-15.524	29.500	16.600	0.000	0.000	0.190
10	0.928	-15.776	9.000	5.800	0.000	0.000	0.000
11	0.943	-15.517	3.500	1.800	0.000	0.000	0.000
12	0.948	-16.011	6.100	1.600	0.000	0.000	0.000
13	0.941	-16.069	13.500	5.800	0.000	0.000	0.000
14	0.915	-17.034	14.900	5.000	0.000	0.000	0.000

Figure 8: The total losses for each bus

Table 2 and figure 8 shows that the total losses for each bus of the system without EG and with EG. The lowest value of the total losses occurs when EG (20MW) is connected to bus No. 9.

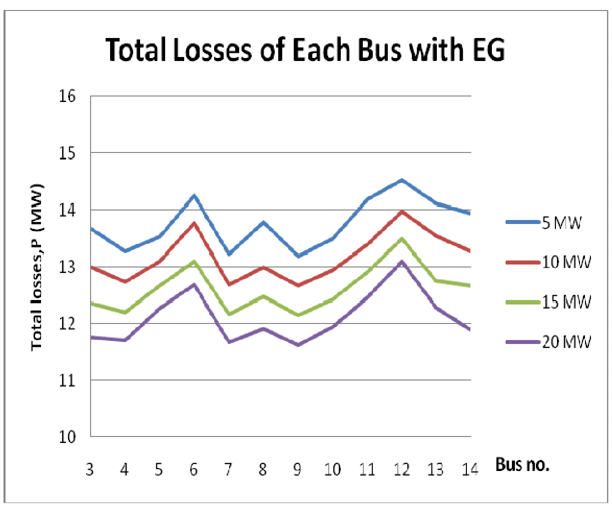

Figure 9: Comparison between the connections of 5 MW, 10 MW, 15 MW and 20 MW of EG

From the result, the connection of the EG to distribution network is proved to reduce the total losses of the system. Without EG, the total losses in MW is 15. 508 MW and with EG 20MW at bus 9 the losses is 11.608 MW. It mean 25.2% reduction in losses in cases without EG. For the different location of EG is connected, the total losses would be different. Based on figure 1, the location of bus 9 is near to the load and this is main factor why this bus become the lowest total losses when connected with EG.

The reduction of network losses depends on the location and the sizes of EG. If a small embedded EG is located close to a large load then the network losses will be reduced as both real and reactive power can be supplied to the load from the adjacent generator. Conversely, if a large embedded generator is located far away from network loads then it is likely to increase losses on the distribution system.

V. Conclusion

Generally, this project has achieved the objectives. The effect of integration of embedded generation into distribution network on the losses reduction has been covered. The EG can have also considerable impact on the existing system particularly in terms of short circuit fault levels, voltage profile and thermal loading circuits. A case study is used to demostrate some of the issues and the need for undertaking studies and planning in future.

VI. Acknowledgment

The authors gratefully acknowledged the staffs in the Laboratory of Electric Machines and Drives as well as Laboratory of Electric Power, UTHM for their valuable contributions towards the success of this work. The authors would like to thank the Research Innovation and Management Center, UTHM for financially supporting this research under the short grant.

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VIII. Biographies

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