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Load Flow Analysis of a Test Distribution: A Case Study

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ABSTRACT

This paper deals with a test distribution system as a project based learning (PBL) task for system load flow studies. The simulation model of the test distribution system is developed using electrical transient analyzer program (ETAP) to analyze the load power flow at different nodes. Interface load flow diagram of the simulation model is developed at 33 kV and 11 kV network. Annual demand, load distribution system, system losses, load duration and changes of losses in various generating unit have been investigated. The developed distribution system provides a solution for improving the load flow of the system and their analysis.

Key words: Distribution system, Load power, renewable distributed generation, voltage profile.

Introduction

Generation, transmission and distribution are the main parts of the power system. The electricity is generated in the power station, which is installed with generators, control and instrumentation equipments, switchgears and other associated plants and equipment's (Sallehhudin *et al*., 2006). Transmission lines are required to transport the bulk electricity from the power stations to various locations to enhance supply reliability as well as to achieve effective utilization of power (Golshan and Arefifar 2006). Transmission of electricity is usually at high voltage so as to reduce transmission losses, substations equipped with transformers are required to step down electricity from high voltages to low voltages to suit the requirements of the various categories of consumers such as commercial, industrial and domestic (Pipattanasomporn *et al*., 2005; Hannan *et al*., 2009). At present the transmission system in Malaysia is at voltages of 66kV, 132kV, 275kV. Electrical energy is distributed to consumers via distribution system. The distribution system represents the final linkage between the consumers and the power stations. The distribution process starts at the termination of the transmission lines at distribution substations (Rau and Zeng 2004; Hannan *et al*., 2012). The voltage is then stepped down by step down transformers to supply to the load centers via the distribution network. The distribution voltages used in Malaysia are 33 kV, 11 kV and 415/240.

This report deals with the test distribution system that was given as project based learning (PBL) task for load flow analysis. Methodologies and a real time simulation of the given task has been developed for audit base case load flow and electromagnetic transient analysis. The aim of this work is to find the proper place for distribution generation system in order to improve the load flow of the entire system, analyze and minimize the losses in the distribution system.

Test Distribution System:

A test distribution system comprises of network operating at medium voltage (MV) and low voltage (LV) levels that obtains power from the transmission network or the grid. In some cases, the distribution network may also have embedded generators connected to it. Most customers are connected to the distribution network at MV or LV levels (Golshan and Arefifar 2006; Hannan *et al*., 2011; Hannan *et al*., 2006; Salam *et al*., 2010). In this project, the distribution network is connected to the grid with some loads being supplied by a remote generating unit. To solve the given tasks in the test distribution system, considerations are made on choosing suitable software for simulation, modeling the system; determine the parameters and assumptions for the system and analyzing the load flow of the system.

The commercial software named ETAP Power System (Electrical Transient Analyzer Program) is used because it is one of the widely used software for industrial power system (Ghani *et al*., 2012; Ghani *et al*., 2012; Ghani *et al*., 2012; Subiyanto *et al*., 2011). In addition to that, it has the capability of designing a power distribution system and also it is suitable in performing load flow and short circuit analysis. The PSCAD/EMTDC software has also been considered for the purpose of load flow study [Hannan and Mohamed

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2005). PSCAD/EMTDC is a powerful and flexible graphical user interface, which is completely integrated to schematically construct a circuit, run simulation, analyze the results, and manage the data with a graphical environment and view the results directly during simulation. It is one of the most powerful and intuitive CAD software packages available.

Load Flow Analysis Model:

Power flow analysis is the fundamental to the study the power systems. A power flow solution is often the starting point for many other types of power system analysis as well as it is an essential ingredient for the studies performed in power system operations (Subiyanto *et al*., 2012). It is very important to know the power flow problem or load flow problem. For a given distribution system, the complex power loads and some set of specifications or restrictions on power generations and voltages are given. The test distribution is to be solved for any unknown bus voltages and unspecified generation and finally for the complex power flow in the network components (Hannan *et al*., 2009; Hannan *et al*., 2012). Additionally, the losses in individual and the total network components are to be calculated. Furthermore, the system is often checked for component overloads and voltages outside allowable tolerances. Before we can do the power flow analysis, some assumptions need to be considered.

Assumptions:

i) At generator, the active power is controlled by speed governor and the voltage magnitude is controlled by voltage regulator. Thus, real power and voltage magnitude are treated as known parameters.

ii) At load bus bars, reasonable approximation is that the load active power demand and reactive power demand are considered as known parameters.

iii) At generator bus bar or reference bus bar, the active and reactive powers are variables to make up system losses.

Based on the model given, total current flowing from bus I into the system is
Ii = IB1 + IB2 + IB3

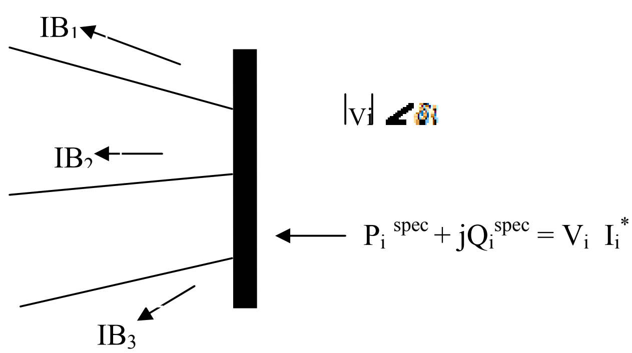

Fig. 2: Power Flow Equations

Complex power injection of the system is based on the equation given below:

$$S_i = S_{Gi} - S_{Di} = Generation - Load \quad (1)$$
$$S_i = \sum_k S_{ik}$$

where $k = 1,2,., n$ and $i = 1,2,\ldots., n$

Similarly phasor current injections are as follows:

$$I_i = I_{Gi} - I_{Di} = \sum_k (Y_{ik} V_{ik}); \quad S_i = V_i I_i^* = V_i \sum_k (Y_{ik}^* V_k^*); \quad (2)$$
$$S_i = \sum_k |V_i||V_k| e^{j\delta ik} (G_{ik} - jB_{ik})$$

Where $V_k = |Vk|e^{j\delta ik}$; $\quad \delta_{ik} = \delta_i - \delta_k$; $\quad Y_{ik} = G_{ik} + jB_{ik}$;

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Breaking the complex power flow equation into real and imaginary parts is as follows:

$$S_i = P_i + jQ_i = \sum_k |V_i||V_k| e^{j\delta ik} (G_{ik} - jB_{ik}) \quad (3)$$
$$P_i = \sum_k |V_i||V_k| [G_{ik} \cos(\delta_{ik}) + B_{ik} \sin(\delta_{ik})]$$
$$Q_i = \sum_k |V_i||V_k| [G_{ik} \cos(\delta_{ik}) - B_{ik} \sin(\delta_{ik})]$$

Load Flow Diagram of Test Distribution System:

The test distribution system operational flow chart is given as in Fig. 3. To find the proper DG allocation in I bus distribution system for voltage profile improvement is the main aim of this procedure. The method is a based on load flow. The sensitive buses to voltage (the buses that have a low voltage magnitude) are considered and ranked in the first step, the aim of this step is to install the DG unit as a FACTs device for voltage control and the DG is placed in all buses & the voltage profile of the entire system in each installation is considered in the second step. After DG installation in each bus, the voltage profiles of all states are ranked from the best state to worst. Finally, task lists are considered to choose the best place to install the DG in a I bus test system to provide a good voltage profile.

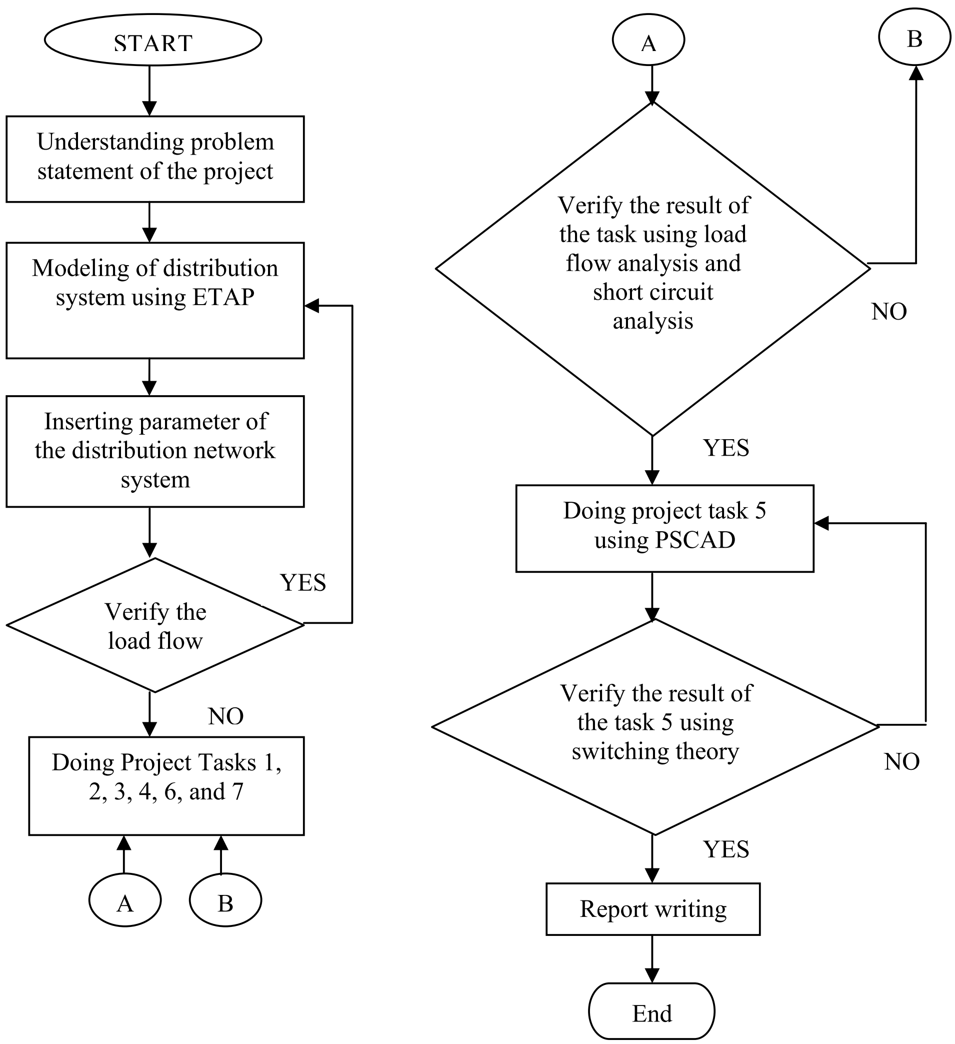

Fig. 3: Operational Flow Chart of Test Distribution System

Results and Discussion

Table 1 and 2 shows the appropriate continuous rating of the circuit breaker and switches respect to the apparent power, voltage and current of the 33 kV and 11 kV network. The load currents are compared with standard of the network. Comparing these two currents show the proper places to install the DG unit for decreasing the losses & improving the voltage profile. For reducing system losses to optimal level of an original system annual demand and loads, the given distribution system is simulated and shown in Table 3 which helps to determine the optimum place to install the Distribution system unit to maintain a minimum loss as well as improve the voltage profile

Table 1: Continuous rating for 33 kV network

Bus	S,MVA	VLL,kV	I_{LL},A	Standard
L31,L32,L30	45	33	787.318917	800
F1,F2,F3,F4	-	33	787.3	800
30,31,32	30	11	1574.63783	1600
1,3,5,7,	-	11	-	1600
2,4,6,8	-	11	-	1600
PPUA	30	33	524.879278	630
PPUB	30	33	524.879278	630
PPUC	15	33	262.439639	630
PPUD	15	33	262.439639	630
PPUAE	30	33	524.879278	630
PPUNEW	15	33	262.439639	630
Main bus		132	20160	800

Table 2: Continuous rating for 11 kV network

Bus	S(MVA)	V_{LL} (kV)	I_{LL} (A)	Standard
Durian	2.5	11	131.22	250
Kelapa	2.5	11	131.22	250
Kgboh	0.3	11	15.75	250
Kgtoh	0.3	11	15.75	250
Teh	0.3	11	15.75	250
Cowan	1	11	52.49	250
Chem	1.5	11	78.73	250
Fabric	1	11	52.49	250
IWK	1.5	11	78.73	250
Aloe	2	11	104.98	250
RTM	2.5	11	131.22	250
Disk	0.75	11	39.37	250
Jong	0.3	11	15.75	250
Shield	0.3	11	15.75	250
Samua	2.5	11	131.22	250
Hospital	0.75	11	39.37	250
Puchong	2.5	11	131.22	250
Sun	2.5	11	131.22	250
Jaya	0.5	11	26.241	250
Paper Mill 1	2.5	11	131.22	250
Paper Mill 2	2.5	11	131.22	250

Table 3: Annual Demand and load for distribution system

Original Distribution System			Power(MW)	
Load (%)	Duration (%)	Index	Demand	Load
100	5	0.05	2.919	2.84295
90	10	0.09	5.253	5.11731
80	25	0.2	11.674	11.3718
75	20	0.15	8.756	8.52885
60	20	0.12	7.005	6.82308
50	10	0.05	2.919	2.84295
40	10	0.04	2.335	2.27436
Annual Total			40.860	39.8013

Table 4 concludes that the annual loss for the original distribution system is (40.86-39.8013) 1.0587 MW. The annual cost of losses is (.0587 MW x RM0.29/kWh x 24 hours x 365 days) RM 2,689,521.48. Therefore, the annual cost of losses for original system is RM 2,689,521.48.

Table 4: Original distribution system annual demand and system losses

Power Before Capacitor installed				
Demand		Loss		
P(MW)	Q(MVAR)	P(MW)	Q(Mvar)	PF (%)
58.372	32.465	1.513	-3.397	87.39

From the load flow analysis result as shown in Fig. 4 at Task 5 (3), for 33 kV network and all 11 kV, where load buses are under the voltage limit. Capacitors are installed to increase the voltage limit to achieve the desire level (90-100%).

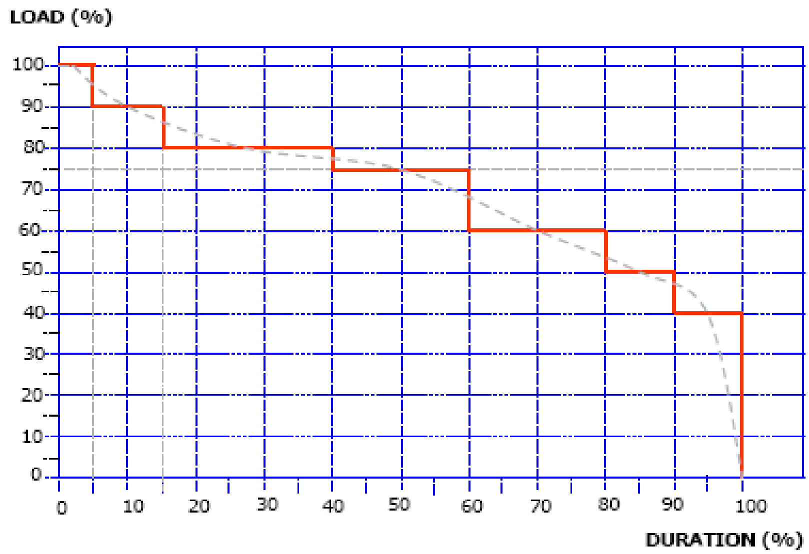

Fig. 4: Load duration for test distribution system

From the simulation result, it can be seen that by varying the output of the generating unit, the system loss and the voltage limit of the connection is influenced. This is because the output power of generating unit is dependent on terminal voltage. Output of generating unit also affects the power loss of the system. Details of power losses before and after the generator used, changes of power and bus voltage are shown in Table 5. Result show that the 1200 kW generating unit does not incurred additional system losses. Terminal voltage at 11 kV bus varies between 11.074kV to 11.123kV. The maximum and minimum voltage limit for 11 kV is 11.55kV (105%) and 10.45kV (95%) respectively. Therefore, it can be considered that there is no voltage limit for 1200 kW generating unit

Table 5: Change of Losses for Variation of Generating Unit

Generator Output	After generator set up System Loss		Before generator set up System Loss		Change		
P (MW)	P (MW)	Q (Mvar)	P (MW)	Q (Mvar)	ΔP	ΔQ	11 kV bus
3000	1.537	-3.83	1.513	-3.397	0.024	0.433	11.103
2500	1.608	-3.715	1.513	-3.397	0.095	0.318	11.176
2000	1.562	-3.789	1.513	-3.397	0.049	0.392	11.123
1800	1.546	-3.816	1.513	-3.397	0.033	0.419	11.111
1700	1.539	-3.828	1.513	-3.397	0.026	0.431	11.104
1600	1.532	-3.838	1.513	-3.397	0.019	0.441	11.097
1550	1.529	-3.843	1.513	-3.397	0.016	0.446	11.093
1530	1.528	-3.845	1.513	-3.397	0.015	0.448	11.093
1500	1.526	-3.847	1.513	-3.397	0.013	0.45	11.091
1450	1.524	-3.852	1.513	-3.397	0.011	0.455	11.087
1430	1.523	-3.854	1.513	-3.397	0.01	0.457	11.086
1350	1.519	-3.86	1.513	-3.397	0.006	0.463	11.081
1300	1.517	-3.863	1.513	-3.397	0.004	0.466	11.077
1250	1.515	-3.866	1.513	-3.397	0.002	0.469	11.074
1200	1.513	-3.869	1.513	-3.397	0	0.472	11.074

Conclusion:

The size and location of distribution system are crucial factors in the application of distribution generation for load flow analysis. In the paper, theoretical and practical approaches have been learned and applied to solve the tasks given. A load flow based simulation using ETAP is developed to find out the optimum location and size of distribution system unit for load profile improvement and minimizing power losses in the test distribution system. The load flow model is developed based on their operating mechanism to calculate annual demands, load duration, losses and changes of losses upon variation of generating unit for 33 kV and 11 kV test distribution system. In addition, optimum location of the distribution generation has been determined for loss reduction and voltage improvement in the distribution system.

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