THE IMPACT OF EMBEDDED GENERATION ON EXISTING ELECTRICAL DISTRIBUTION NETWORK.

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MAY 2007

"I hereby declared that I have read through this report and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

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THE IMPACT OF EMBEDDED GENERATION ON EXISTING DISTRIBUTION NETWORK

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ABSTRACT

Embedded generation (EG) is used renewable energy source to power up electricity to the consumer. Small Renewable Energy Programme (SREP) has approved the use of renewable energy in Malaysia such as wind, solar, municiple waste, biogas and biomass. The EG is connected t0 the 11 to 33kV distribution network in national grid. There is an interuption or disturbance to the grid when the EG is connected to the grid and dispatch the power to the consumer. Therefore the interuptions to the grid are such power flow, power quality, earthing, fault level contribution, interface protection and transient stability. This project is conducted to perform load flow and transient stability analysis on the existing distribution ntwork of Universiti Teknikal Malaysia Melaka (UTeM), i.e Faculty of Electrical Engineering (FKE) and Faculty of Electronic and Computer Engineering (FKEKK). Performance of the system in terms of the power flow, system stability, power quality as well as contingency (n – 1) condition is compared between the system with and without EG.

ABSTRAK

Tenaga elektrik yang dijana kepada pengguna oleh tenaga yang boleh diperbaharui di panggil *'Embedded generation'* atau EG. *Small Renewable Energy Power Programme* (SREP) meluluskan penggunaan tenaga yang boleh diperbahrui di Malaysia seperti angin, solar, bahan buangan, biogas dan biomass. EG disambungkan pada sistem pengagihan bervoltan 11 hingga 33 kV di dalam sistem pengagihan negara. Sistem pengagihan akan mengalami gangguan disebabkan daripada EG yang disambungkan kepada sistem pengagihan. Gangguan yang diterima pada sistem pengagihan adalah aliran kuasa kualiti kuasa, pembumian, aras gangguan, sistem perlindungan dan kestabilan transien. Projek ini dijalankan untuk membuat analisis aliran kuasa dan kestabilan transien pada sistem pengagihan di Universiti Teknikal Malaysia Melaka (UTeM) menggunakan perisian ERACS. Dimana sistem pengagihan UTeM mempunyai dua beban iaitu Fakulti Kejuruteraan Elektrik (FKE) dan Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer (FKEKK). Prestasi sistem ini di analisa mengikuti terma-terma aliran kuasa, kestabilan sistem, kualiti kuasa dan keadaan kontingensi (n – 1) dibandingkan samada EG disambungkan atau tidak dalam sistem pengagihan.

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CHAPTER 1

INTRODUCTION

1.1 Background and Problem Statement

In the Eighth Malaysian Plan, renewable energy (RE) was announced as the fifth fuel in the new Five Fuel Strategy in the energy supply mix. It is targeted that RE will contribute 5% of the country's total electricity demand by the year 2005, that is by the end of the Eighth Malaysia Plan period. With this objective in mind, greater effort is being undertaken to encourage the utilization of renewable resources, such as biomass, biogas, solar and mini-hydro, for energy generation.

A programme aimed at increasing public awareness of the positive attributes of RE and energy efficiency (EE) measures is being carried out by the Centre for Education and Training in Renewable Energy and Energy Efficiency (CETREE), University Science Malaysia, Penang. The government is currently working on 'hands-on' applications of RE with a number of on-going projects.

Table 1: A recent renewable study identified the renewable energy resource potential in the country, in ringgit value [6].

Renewable Energy Resource	*Energy Value in RM Million(Annual)*
Forest residues	**11,984**
Palm oil biomass	**6,379**
Solar thermal	**3,023**
Mill residues	**836**
Hydro	**506**
Solar PV	**378**
Municipal waste	**190**

Rice husk	**77**
Landfill gas	**4**

Palm oil wastes are the biggest resource that can be easily develop. The fact has been identified by Ministry of Energy, Water and Communications. Solar is another important option, particularly for rural electrification and water heating.

The Small Renewable Energy Power Programme (SREP) has been launching by government on 11th May 2001. The launch of the Programme is among the steps being taken by the Government to encourage and intensify of the utilisation on Renewable Energy in power generation. The Government's decision to intensify the development of Renewable Energy as the fifth fuel resource under the country's Fuel Diversification Policy, as stipulated in the objectives of the Third Outline Perspective Plan for 2001-2010 (OPP3) and the Eight Malaysia Plan.

Small power generation plants which utilise Renewable Energy can apply to sell electricity to the Utility through the Distribution Grid System. Project developers are required to negotiate directly with the relevant Utility on all aspects relating to the Renewable Electricity Purchase Agreement, including the selling price on a "willing-seller, willing buyer" and "take and pay" basis [7]. The producers will be given a licence for a period of 21 years, thus will be effective from the date of commissioning of the plant. Under this Programme, the utilization of all types of Renewable Energy, including biomass, biogas, municipal waste, solar, mini-hydro and wind, are allowed.

The maximum capacity of a small Renewable Energy plant is designed to sale power to the grid must be 10 MW. The power plant design can be more than 10 MW in size, but the maximum capacity that being allowed for power export to the distribution grid must not more than 10 MW.

The development of Renewable Energy as the country's fifth fuel resource, a Special Committee on Renewable Energy (SCORE) has been set up under the Ministry of Energy, Communications and Multimedia to co-ordinate the implementation of the Government's intensify.

The problem that has been expected is utilities will get benefits in terms of power loss reduction, power quality improvement and power flows. However, some importance issue must be taken into consider as power flow, power quality, fault level contribution, transient stability, interface protection and earthing. Thus, this has led to the conduction of this project.

1.2 Objectives

This project is conduct to performed analysis on UTeM distribution network. The distribution consist loads of substation FKE and FKEKK. The analysis performs using ERACS which is the most efficient and suitable power system computer software. Load flow analysis was analyzed when the system is with and without the EG dispatch its power to the system. On the other hand, the analysis was also perform to analyze wheter the distribution are stabile when the loads at maximum demands. The distribution also being analyze on it strength acceptance when the EG is connected on the distribution with it maximum power. Besides the load flow, transient stability was also performed on the distribution. The analysis were conduct during the EG is connected and disconnected on the distribution.

1.3 Scope

The scope of this project is performed load flow analysis and power system stability analysis on Universiti Teknikal Malaysia Melaka (UTeM) system distribution. This analysis performed on two loads of UTeM system which has FKEKK and FKE. Those loads are in different voltage rating which is at FKEKK and FKE is 415V and 433V rated.

1.4 Methodology

i. Finding references that related to the topics.
ii. Literature review and reading the references that related to the topics.
iii. Study on power system simulation software available and selected the one that is convenient for this project.
iv. System development and simulation using selected software.
v. Simulated the system.
vi. Perform analysis that related in this project.
vii. Final report preparation.
viii. Project presentation.

1.4.1 Simulation software selection

Simulation software was chosen for available and convenient to the project. Since there are many power system simulation software, that software is being studied and small distribution system is performed. As a result, the power system simulation software were used in this project are ERACS.

1.4.2 System development

Power system distribution network was developed using ERACS. So the analysis is being performed throughout the simulation. The data of the system are taken from Development and Asset Management office of UTeM. The distribution was built in the power system software.

1.4.3 Simulation

The distribution network is being simulated on load flow and power system stability analysis. Besides that the distribution where analyze weather the distribution can maintain it strength when there is any disturbance.

1.4.4 Analysis

The load flow and power system stability analysis will be performed on the system that has been developed. The results will be collected and the results will be analyzed.

CHAPTER 2

LITERATURE REVIEW

2.1 The impact of embedded generation on design, operation and protection of distribution network.

Embedded generation has increased by number since 1983 Energy Act. The most common location have been connencted to low voltage such as 6.6 or 11 kV network by large industrial work which used high heat and smaller CHP.

Some of embedded generation have the potencial to become integral and contributing part of the network. To achive this more sympathetic network design and operation is required to utilies then to improve network performance and security. Non-valid operation on feeders and interconnection of transformer offer an immediate means to increase capacitive and accommodate generation. However there must be collaboration between PES and generation if the end result is to remain a safe and cost efficient system.

The security impact will be eased if the more significant embedded generation are operated in network support roles with more stable interfacing. Some generation with appropriate protection and earthing, if required operate islanded with low risks from out of synchronism reclosing. In such case. Loss of mains detaction system which have proved vulnarable to operation during national frequency excursions are not required.

Voltage support and loss reduction are technically achievable even in some extreme situation. Connection agreement may include daily shcedualling of generation and should be flexible to adapt to changing network requirement, load patterns and risks. In addition of operational imformation must ber readily exchanged between PES and generation closely associated with each other in sections of a distribution network if disturbing interactions are to be avoided.

2.2 The impact of embedded generation on distribution network.

Small-scale embedded generation in the guise of combined heat and power (CHP) equiptment is being implemented increasely in UK. The predictable effect of embedded generation is:

i. An increasing in the fault leval.
ii. Change in the voltage profile.
iii. Change in the power flows.
iv. The possibility of 'islanding' an area under mains failure conditions.
v. Change in the network's losses.

There are some of the possible future effects of embedded generation on distribution network. The possible effect is:

i. Network stability
ii. Fuel cells

From small-scale generation point of view, embedded generation should have as small an impact as possible on the distribution networks. This significantly causes the installation problem of on-site generation.

Reverse Power flows back on to the network are to be avoided if at all possible, not just because they may cause problems to the REC's because they are generally uneconomic for the customers.

CHAPTER 3

LOAD FLOW ANALYSIS

3.1 Introduction

The load flow study in a power system deals with steady-state analysis of an interconnected power system during normal operation.A succesful power system operation under normal balanced three-phase steady-state condition requires the following:

i. Generation supplies the demand (load) plus losses.
ii. Bus voltage magnitudes remain close to rated values.
iii. Generators operate within specified real and reactive power limits.
iv. Transmission lines and transformer are not overloaded.

Load flow analysis, provides information about electrical performance, power flow (real and reactives), transmission lines loading, transformer loading and losses. Futhermore, the study is an alternative plan for future expansion to meet demands and new generation proposed to the system.

The node-voltage methods are commently used in load flow study. Therefore, a bus is a node at any system which has one or more transmission lines, loads and generators that are connected.

The load flow study is the backbone of power system analysis for planning, operation, economic scheduling and exchange of power between utilities. In other hand, load flow analysis is required for other analysis such as transient stability and contingency studies.

3.2 The power-flow problem

The load flow study problem consist of determine the voltage magnitude and phase angle at each bus in power system under balanced three-phase conditions. Besides that, real and reactive power flow can be determined in this study.

In solving the load flow problem, which the starting point is a single line diagram of the power system.The following four variables are associated with each bus *k* that being shown in figure 1. The four variables are:

i. Voltage magnitude, V_k
ii. Phase angle, δ_k
iii. Net real power, P_k
iv. Net reactive power, Q_k supplied to the bus.

There are two of these variables that specified as input data, meanwhile the other two are unknowns to be computed. So, the power deliverd is separated into generator and load terms. In figure 3.1, the power deliverd to bus *k* is:

$$S_k = S_{Gk} - S_{Lk}$$

$$P_k = P_{Gk} - P_{Lk}$$

$$Q_k = Q_{Gk} - Q_{Lk} \quad (3.1)$$

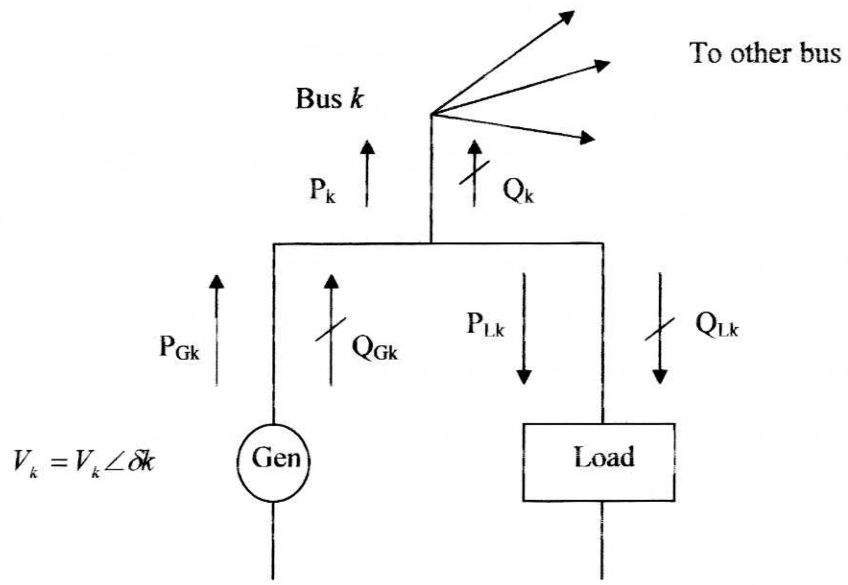

Figure 3.1: Bus variables V_k, δ_k, P_k, and Q_k

Note that, the subscipt G and L in equation (3.1) are referd to generator and load to bus k. Each of bus k is categorized into the following three bus type:

1. Swing bus – There is only one swing bus or slack bus. This bus is taken reference bus where $V_1 \angle \delta_1$ typically $1.0\angle 0^0$ per unit, is input data. The power-flow program computes P_1 and Q_1.
2. Load bus – At this bus, the real and reactives power are specified. Therefore, P_k and Q_k are input data. This bus also known as bus PQ. Besides that, the load flow study computes V_k and δ_k.
3. Voltage controlled bus – Examples of this bus are generators, switched shunt capacitors or static VAR systems that connected to the system. P_k and V_k are input data while Q_k and δ_k are computes in load flow study. The maximum and minimum VAR limits Q_{Gkmax} and Q_{Gkmin} of this equipment are also input data. The other example is a bus to which a tap-changing transformer is connencted, the tap setting are compute in load flow study.

From equation (3.1), when bus *k* is a load bus without generation, $P_k = -P_{Lk}$. This means the real power supplied to bus *k* is negative. If the load is inductive, $Q_k = -Q_{Lk}$, which is mean is negative.

A transmission lines are represented by the equivalent π circuits. The input data are from series impedance and shunt impedance in per unit, so the two buses are connected to the transformer and MVA rating is maximums. Besides, transformers are also represented by equivalent π circuits. So, the input data are same as before in each transformer. In case of tap-changing transformer, the input data include maximum tap setting. As the statement, only bus admittance matrix, Y_{bus} being used. It can be constructed from the line and transformer input data. The elements of Y_{bus} are:

Diagonal elements: Y_{kk} = -*j*(sum of admittance connencted to bus *k*)

Off-diagonal elements: Y_{kn} = - *j*(sum of admittance connected between buses *k* and *n*)

$$k \neq n \tag{3.2}$$

3.3 The load flow solution

There are two main methods for load flow solution, those are Gauss-Seidel and Newton-Raphson. The typical methods that being used in load flow study is Newton-Raphson because of the advantages of Newton-Raphson are higher than Gauss-Seidal.

In load flow study, the nodal equation in power system is:

$$I = Y_{bus}V \tag{3.3}$$

for bus *k*, the equation is:

$$I_k = \sum Y_{kn}V_n^* \tag{3.4}$$

The complex power is supplied to bus k is:

$$S_k = P_k + jQ_k = V_k I_k^* \qquad (3.5a)$$

$$P_k + jQ_k = V_k\left(\sum Y_{kn} V_n\right) \qquad (3.5b)$$

where $k = 1, 2, \ldots, N$

3.4 Gauss-Seidel methods

In load flow study, it is necessary to solve the set of nonlinear equations. Since the data consist of P_k and Q_k for load or voltage-controlled buses, the nodal equiations should not directly fit the linear equation format. During the power flow through in bus k, the current, I_k can be compute by:

$$I_k = \frac{P_k - jQ_k}{V_k^*} \qquad (3.6)$$

From equation (3.5) and (3.6), the voltage, V_k in each bus can be compute by

$$V_k(i+1) = \frac{1}{Y_{kk}}\left[\frac{P_k - jQ_k}{V_k^*} - \sum Y_{kN} V_N(i+1) - \sum Y_{kN} V_N(i)\right] \qquad (3.7)$$

At voltage-controlled bus, Q_k is unknown so it can be compute by

$$Q_k = V_k(i)\sum Y_{kN} V_N(i)\sin[\delta_k(i) - \delta_N(i) - \theta_{kN}] \qquad (3.8)$$

As we know $Q_{Gk} = Q_k + Q_{Lk}$, so it compute must not exceed its limit $Q_{Gk\max}$ or $Q_{Gk\min}$. To compute new value V_k in this bus is $V_k(i+1) = V_k(i+1)\angle\delta_k(i+1)$.

3.5 Newton-Raphson method

In order to use Newton-Raphson method in load flow study, nonlinear equations $y = f(x)$ are solved in Newton-Raphson. As a result, the *x*, *y* and *f* vector for are define as

$$x = \begin{bmatrix} \delta \\ V \end{bmatrix} = \begin{bmatrix} \delta_2 \\ \delta_N \\ V_2 \\ V_N \end{bmatrix}; \; y = \begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} P_2 \\ P_N \\ Q_2 \\ Q_N \end{bmatrix};$$

$$f(x) = \begin{bmatrix} P(x) \\ Q(x) \end{bmatrix} = \begin{bmatrix} P_2(x) \\ P_N(x) \\ Q_2(x) \\ Q_N(x) \end{bmatrix} \quad (3.9)$$

where V, P, and Q terms are in per-unit and δ terms are in radians. For swing bus variables δ_1 and V_1, the variable are omitted from equation (3.9). Since the variable of the swing bus are already known. To omit, the imaginary and real in equation by

$$y_k = P_k = P_k(x) = V_k \sum Y_{kN} V_N \cos(\delta_k - \delta_N - \theta_{kN}) \quad (3.10)$$

$$y_{k+N} = Q_k = Q_k(x) = V_k \sum Y_{kN} V_N \sin(\delta_k - \delta_N - \theta_{kN})$$

$$k = 2,3\ldots,N \quad (3.11)$$