STATIC AND DYNAMIC IMPACTS OF SHUNT CAPACITOR PLACEMENT IN DISTRIBUTION SYSTEMS

RAFIDAH BINTI ABDUL KADIR

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Faculty of Electrical & Electronics Engineering
University Malaysia Pahang

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"I hereby acknowledge that the scope and quality of this thesis is qualified for the award of the Bachelor Degree of Electrical Engineering (Power Systems)"

Signature : ______________________________

Name : MOHD REDZUAN BIN AHMAD

Date : 23 NOVEMBER 2009

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Signature : ______________________________

Author : RAFIDAH BINTI ABDUL KADIR

Date : 23 NOVEMBER 2009

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ABSTRACT

Adding capacitors to power system distributions provides well known benefits, including power factor correction, voltage support and increase of active power transfer capacity. This thesis will presents the static and dynamic impacts of shunt capacitor placement in distribution systems by describes measurements and studies performed before and after the installation of 49.46MVAr capacitor banks in 4-bus test system and a 37.92MVar capacitor banks in-9 bus test systems. A load flow analysis is conducted to predict power flow magnitudes, power factor, voltage levels and losses in branches of the system. The results are used to determine the size of capacitor banks to maintain an acceptable power factor and or voltage level to measure the power losses before and after capacitor bank installation. The fault analysis also been studied by applying single line to ground fault to see the impacts when fault applied before and after installation of capacitor bank since most of researcher did not include the capacitors in fault studies. Switching transients analysis were also studied since the capacitor switching transient can be very damaging and costly problems where the transient voltage on the power system causes the power and voltage flows in the system to change from the steady-state value. Thus in order to take appropriate pre-cautions in real system, it is necessary and advantageous to analyze and determine the worst case switching transients before the actual switching take place. In this thesis, 2 test systems which were developed for power flow analysis was used to examine characteristics of transient voltage by using 3 set of different size of capacitor bank. The basic fundamental method to reduce the transient voltage also been investigated. The results of measurements are compared to the ones obtained by studies and simulations. The modeling and transient simulation were carried out by using MATLAB and PSCAD software.

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ABSTRAK

Menambah kapasitor ke sistem kuasa pengagihan memberi banyak faedah, termasuk pembetulan faktor kuasa, sokongan voltan dan peningkatan keupayaan pindahan kuasa aktif. Tesis ini membentangkan beban statik dan kesan dinamik apabila penempatan kapasitor dalam sistem pengagihan bagi mengkaji kesan sebelum dan selepas pemasangan 49.46MVAr kapasitor bank dalam 4 bas uji sistem dan satu kapasitor 37.92MVar bank dalam 9 bas sistem uji. Satu analisis aliran beban dijalankan bagi meramalkan magnitud aliran kuasa, faktor kuasa, aras voltan dan kerugian dalam cawangan-cawangan sistem itu. Keputusan tersebut digunakan bagi menetapkan saiz kapasitor bank untuk mengekalkan satu faktor kuasa yang boleh diterima dan aras voltan untuk mengukur kuasa kerugian sebelum dan selepas bank kapasitor dipasang. Analisis ganguan juga telah dikaji dengan menggunakan garis tunggal ganguan ke bumi untuk melihat kesan sebelum dan selepas pemasangan bank kapasitor. Kebanyakan penyelidik tidak melakukan kajian ganguan keatas kapasitor. Analisis Transient pensuisan juga dikaji apabila pensuaisan kapasitor bank boleh menjadi masalah yang sangat besar dalam merosakkan barang elektrik malah voltan yang mengalir itu mampu mengubah nilai voltan dalam sistem. Dalam tesis ini, 2 sistem uji dimodel untuk menganalisis aliran kuasa dan mengkaji ciri-ciri voltan transient dengan menggunakan 3 set bank kapasitor saiz yang berbeza. Kaedah dasar asas untuk mengurangkan voltan transient juga disiasat. Keputusan bagi ukuran dibandingkan dengan keputusan yang diperolehi dari kajian dan simulasi. Model dan simulasi transient dijalankan dengan menggunakan perisian MATLAB dan PSCAD.

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LIST OF SYMBOLS

C	-	Capacitance
f	-	Frequency
I	-	Current
L	-	Inductance
P	-	Real Power
pf	-	Power factor
p.u	-	Per unit
Q	-	Reactive Power
S	-	Apparent Power
s	-	Second
T	-	Time
V	-	Voltage

LIST OF ABBREVIATION

AI	-	Artificial Intelligence
DM	-	Decision Maker
DC	-	Direct Current
FIS	-	Fuzzy Inference System
GA	-	Genetic Algorithms
L	-	Low Voltage
MV	-	Medium Voltage
SA	-	Simulated Annealing
TS	-	Tabu Search
TNB	-	Tenaga Nasional Berhad

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CHAPTER 1

INTRODUCTION

1.1 Overview of The Project

Studies have indicated that as much as 13% of total power generated is consumed as I^2R losses at the distribution. Reactive currents account for a portion of these losses. However, the losses produced by reactive currents can be reduced by the installation of capacitor banks. Capacitor banks have long be used to provide voltage support, provide reactive power compensation and to correct displacement power factor on utility distribution systems. They are provided to minimize power and energy losses, maintain best voltage regulations for load buses and improve system security. The requirement of new usages and unregular usage of power, leads to use the maximum energy in the system. Somehow the usage can reach its maximum level by adding shunt capacitor which can avoid the VAR and I^2R problem on this case. However we will lose some energy when we charge those capacitors. To avoid this loss we are able to switch those capacitors when required only.

Capacitor banks are connected either directly to the high voltage bus or to the tertiary winding of the main transformer. Switching off capacitor banks provides a convenient means of controlling transmission system voltages. They are normally distributed throughout the transmission system so as to minimize losses and voltage drops.

Due to their widespread applications, capacitor switching transients are the most common transient events on the power system, second only to voltage sag disturbances and many more. Capacitor switching operations are frequently correlated with problem such as nuisance tripping of adjustable speed drives, process controls, and any load that cannot tolerate sub cycle overvoltage transients.

Unfortunately, most utilities have limited resources to indentify these problems and correlate them with the capacitor switching operations. Moreover, among for those that have the capability, the switched capacitor bank involved in the problem cannot be determined since the necessary methodology is not available.

So that, the problem is very much linked to the placement of capacitors in the distribution system which is essentially by determination of the location, size, number and type of capacitors to be placed in the system. A large variety of research work has been done on capacitor placement in the past. All the approaches differ from each other by the way of their problem formulation and the problem solution method employed. It may not possible to locate a given capacitor exactly at the most desirable position if the static and dynamic impacts of the capacitor placement are not taken into account. This is because there are many impacts of placement of the capacitor such as voltages drop, power losses, transient stability, that occurrence in the power distribution system.

Hence, the analytical method using MATLAB and PSCAD will be done to find out is there are any impacts in load flow, fault occurrence and transient stability if we locate the capacitor bank in the busbar which is nearer to load at the distribution systems. However, the method is by collecting the data from input data of MATPOWER 3.2 from MATLAB in order to obtain the load flow analysis then model a test systems based on the data for fault analysis and transient analysis.

Finally, the comparison of the capacitor placement is presented to compare between the obtain result using capacitor bank and without capacitor bank at the system. Hence, establish the impacts of adding capacitor bank at the system by analyze the power losses, maximum current when applying fault and transient when capacitor switching.

1.2 Literature Review

This chapter is also reviews the previous works done by researches on find out optimal shunt capacitor placement in the distribution systems. There is also some other key point on how to model any systems in PSCAD. The optimal capacitor placement was focus on cost and benefits in distribution systems. Many of the previous researches employed simplifying assumptions to simplify the problem formulation, although these assumptions may diverge the computed results to the actual real time solution.

Hence, optimal capacitor placement problem is a well research topic among researches. Earlier approaches differ from each other by the way of their problem formulation, methodology and the problem solution methods employed. Each methodology has certain advantages and drawbacks. It was concluded on their works that a switched capacitor is indeed needed for distribution system where the load level varies with time.

1.2.1 Conventional Method for Shunt Capacitor Placement

The capacitor placement studies will then be classified into four major methods which are mathematical method, numerical programming methods, heuristics methods and AI based methods.

1.2.1.1 Analytical Methods

All the early works of optimal capacitor placement used analytical methods. It was from these early researches that the famous “two-thirds” rule became established. These algorithms were devised when powerful computing resources were unavailable or expensive. Analytical methods involve the use of calculus to determine the maximum savings from capacitor placement.

Although simple closed-form solutions were achieved, these methods were based on unrealistic assumptions like constant conduction size, uniform loading, and capacitor placement locations and sizes are modelled as continuous variables.

1.2.1.2 Numerical Programming Methods

As computing power become more readily available and computer memory less expensive, numerical programming methods were devised to solve optimization problems. Numerical programming methods are iterative techniques used to maximize (or minimize) an objective function of decision variables. For optimal capacitor allocation, the savings function would be the objective function and location, sizes, number of capacitors, bus voltages and currents would be the decision variables which must satisfy operational constraints.

Some of the numerical programming methods have the advantage of considering feeder node locations and capacitor sizes as discrete variables which is an advantage over analytical methods. However, the data preparation and the interface development for numerical techniques may require more time than analytical methods. The convexity of the capacitor placement problem must also be determined to determine if the results yielded by a numerical programming technique is a local or global extremum.

1.2.1.3 Heuristics Methods

Heuristics are rules of thumb that are developed through intuition, experience and judgement. Heuristics rules produce fast and practical strategies which reduce the exhaustive search space and can lead to a solution that is near optimal. Heuristics methods are intuitive, easy to understand and simple to implement as compared to analytical and numerical programming methods. However, the results produced by heuristics algorithms are not guaranteed to be optimal.

1.2.1.4 Artificial Intelligence (AI)-Based Methods

The recent popularity of Artificial Intelligence (AI) has led many researchers to investigate for power engineering application such as the use in optimal capacitor allocation and other engineering problems. AI seeks, as its main goal, to create artificial system which mimics aspects of human behaviour, such as perception, evolution, memory, learning, adaptability and reasoning. Moreover, AI techniques are simpler to implement.

Such AI based methods are genetic algorithms (GAs) where the GA model emulates biological evolutionary theories of genetic inheritances and Darwinian strife for survival. These models require four basic elements of Initial population, evaluation of the fitness, selection, and genetic operators which includes crossover and mutation. The method is only apply on radial distribution networks characterized by unbalanced line-to-neutral loads, varying loads over time, contains three-phase, two-phase and single-phase lateral feeders, and involves mutual coupling between conductors [6]. Normally only balanced three-phase capacitor bank is applied on buses with all of the three-phase wires present and a single-phase shunt capacitors for single-phase or two-phase laterals.

Meanwhile, simulated annealing is particularly well suited for a large combinatorial optimization problem since it can avoid local minima by accepting improvements in cost. However, it often requires a meaningful cooling schedule and a special strategy, which makes use of the property of distribution systems in finding the optimal solution. [7] They were augment the cost function with the operation condition of distribution systems, improve the perturbation mechanism with system topology, and use the polynomial-time cooling schedule, which is based on the statistical calculation during the search. The validity and effectiveness of the proposed methodology is demonstrated in the Korea Electric Power Corporation's distribution system.

A Tabu Search (TS) based also approached to provide decision support in the problem of capacitor allocation in radial distribution networks is presented [8]. The model explicitly considers two conflicting and incommensurate objective functions, related to cost and operations aspects of evaluation. This offers the decision maker (DM) the possibility both to expand the range of potential alternative solutions and to express his/her preferences to select a satisfactory compromise solution. A multi-objective approach to the capacitor allocation problem in radial distribution systems is described [8]. The aim of this work is to provide decision support in the placement and dimensioning of capacitors, taking into account two conflicting objectives: minimizing line losses (resistive) and minimizing capacitors costs (acquisition, installation, operation and maintenance). The proposed methodology uses a Tabu Search based algorithm to decide the locations to install capacitors (number and place) and the sizes of capacitors to be installed. The methodology is applied to a test case of an actual radial distribution system.

It is derived from fuzzy set theory dealing with reasoning that is approximate rather than precisely deduced from classical predicate logic [9]. [10] Presents a fuzzy approach to determine suitable locations for capacitor placement. Two objectives are considered while designing a fuzzy logic for identifying the optimal capacitor locations. The two objectives are to minimize the real power loss and to maintain the voltage within the permissible limits. Voltages and power loss indices of distribution system nodes are modeled by fuzzy membership functions. A fuzzy inference system (FIS) containing a set of rules is then used to determine the capacitor placement suitability of each node in the distribution system. Capacitors can be placed on the nodes with the highest suitability.

For the capacitor placement problem, approximate reasoning is employed in the following manner where, when losses and voltage levels of a distribution system are studied [11], an experienced planning engineer can choose locations for capacitor installations, which are probably highly suitable. For example, it is intuitive that a section in a distribution system with high losses and low voltage is highly ideal for placement of capacitors. Whereas a low loss section with good voltage is not ideal for capacitor placement. A set of fuzzy rules has been used to determine suitable capacitor locations in a distribution system.

1.2.2 Load Flow Analysis According IEEE Standard

A load flow solution determines the bus voltages and the flows in all branches for a given set of conditions. A load flow study is a series of such calculations made when certain equipment parameters are set at different values, or circuit configuration is changed by opening or closing breakers, adding or removing a line and many more. Load flow studies are performed to check the operation of an existing system under normal or outage conditions, to see if the existing system is capable of supplying planned additional loads, or to check and compare new alternatives for system additions to supply new load or improve system performance [21].