STATIC SECURITY ASSESSMENT IN DEREGULATED POWER SYSTEM USING ARTIFICIAL INTELIGENCE TECHNIQUES

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A thesis submitted in fulfillment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
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NOVEMBER 2009

ABSTRACT

The basic function of an electric power system is to supply customers with electric energy as economically as possible and with a reasonable degree of continuity and quality. Deregulation of power system in recent years has turned static security assessment (SSA) into a challenging task for which acceptably fast and accurate assessment methodology is essential. The objective of this research is to investigate the reliability of the SSA in determining the security level of power system from serious interference during operation. In this research, three types of Artificial Intelligence (AI) techniques namely Artificial Neural Network (ANN), Adaptive Neuro-Fuzzy Inference System and Decision Trees are implemented to classify the security status in the test power system, comparison are made in terms of computation time and accuracy of the networks. Data obtained from Newton Raphson Load Flow (NRLF) analysis method are used for the training and testing purposes of the proposed AI techniques. The data are used also as a benchmark to validate the results from AI techniques to achieve high speed of execution and good classification accuracy. A new methodology of feature selection technique based on extracting variables has also been applied. The proposed techniques have been extended and tested on 5, 30, 57 and 118 IEEE test systems. The deregulated system is configured into base case, pool and bilateral contract modes in order to evaluate the effectiveness of the proposed techniques for SSA on deregulated power system. Generally, the proposed AI techniques have successfully been applied to evaluate SSA for various IEEE test system configured as deregulated systems. These techniques are as accurate as NRLF techniques but with shorter computation time. It is found that the ANN is well suited for online SSA of deregulated power systems amongst the three methods applied.

ABSTRAK

Fungsi asas sistem kuasa adalah untuk membekalkan tenaga elektrik yang berterusan dan berkualiti kepada pengguna secara ekonomi. Dalam beberapa tahun kebelakangan ini, penyahaturan ke atas sistem kuasa telah menyebabkan bidang penaksiran keselamatan statik (SSA) semakin mencabar di mana kaedah penaksiran ke atas sistem perlu dilakukan dengan pantas dan tepat. Objektif penyelidikan ini adalah untuk mengkaji keboleharapan SSA dalam menentukan paras keselamatan sistem kuasa daripada gangguan yang teruk semasa dalam operasi pengendalian. Penyelidikan ini telah menggunakan tiga teknik Kecerdikan Buatan (AI) yang merangkumi Rangkaian Neural Buatan, Rangkaian Suai berdasarkan Sistem Inferens Neuro-Fuzzy Adaptif dan jenis akar pokok keputusan di mana perbandingan antara teknik tersebut telah dilakukan untuk mengelaskan tahap keselamatan dalam sistem kuasa ujian dengan mengambilkira masa pengiraan dan ketepatan rangkaian tersebut. Data daripada kaedah Aliran Beban Newton Raphson (NRLF) digunakan untuk melatih, menguji dan membanding teknik yang dicadangkan. Semua data telah digunakan sebagai masukan pada pengujian dan latihan AI. Untuk mencapai kelajuan tinggi dalam pelaksanaan dan ketepatan pengkelasan yang baik, kaedah baru teknik pemilihan sifat juga digunakan. Algoritma diuji ke atas kajian kes sistem ujian IEEE bas 5, 30, 57 dan 118. Kes asas, pengumpulan dan kontrak duahala telah digunakan untuk menilai kemampuan teknik yang dicadangkan. Secara amnya, teknik AI yang dicadangkan telah berjaya diaplikasikan bagi menilai SSA untuk kepelbagaian konfigurasi pengujian sistem IEEE dalam penyahaturan sistem kuasa. Adalah didapati bahawa teknik yang dibangunkan ini menpunyai ketepatan yang sama dengan NRLF dan lebih baik daripada segi masa pengiraan. Adalah didapati juga bahawa antara tiga teknik tersebut, teknik ANN adalah paling sesuai untuk SSA di atas talian dalam sistem kuasa penyahaturan.

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LIST OF ABBREVIATIONS

ANFIS	-	Adaptive Neuro-Fuzzy Inference System
AC	-	Alternative Current
ANN	-	Artificial Neural Network
AI	-	Artificial Intelligence
BPNN	-	Back-propagation Neural Network
CPNN	-	Counter propagation Neural Network
DT	-	Decision Tree
DC	-	Direct Current
DisCos.	-	Distribution Companies
DSA	-	Dynamic Security Assessment
EMS	-	Energy management System
ES	-	Expert System
FDLF	-	Fast Decoupled Load Flow
FIS	-	Fuzzy Inference System
FS	-	Fuzzy System
GenCos.	-	Generation Companies
ISO	-	Independent System Operator
IEEE	-	Institute of Electrical and Electronic Engineering
KB	-	Knowledge Base
KSOM	-	Kohonen Self Organizing Map
LS	-	Learning Set
ML	-	Machine Learning
MCP	-	Market Clearing Price
MSE	-	Mean Square Error
MF	-	Member Function
MLP	-	Multilayered Perception

CHAPTER 1

INTRODUCTION

1.1 General Consideration

Power systems of today are highly complex system network, sometimes made of thousands of buses and hundreds of generators [1]. The three main components of power system are generation, transmission and distribution systems in interconnected networks. Generating electricity is by the generation systems delivering the generated electricity to distribution systems for supplying load over wide geographical areas done by transmission systems.

The principle task of an electric power system is to deliver the power requested by the customers, without exceeding the acceptable voltage and frequency limits. This task has to be solved in real time and in a safe, reliable and economical manner. Primary and most basic aim of power system operator's is to schedule the available generating resources, such that the load demand is met at the least operating cost. One eventuality that can prevent economic operation of power system is the inability of the transmission network to transfer the scheduled power, without any of its limiting criteria being violated. This is more likely to occur in the event of the network being subjected to an external disturbance, but could also occur during steady state.

The traditional electric power industry around the world has been operated in a vertically integrated environment. Nowadays, a deregulated environment is one where the generation, transmission and distribution of electricity are owned and operated by independent business entities. A market structure is established to facilitate the buying and selling of electricity like a commodity. The introduction of competition is expected to improve efficiency and operation of power systems.

This shift in electric energy sector from vertically integrated to deregulation, with the intention to improve operation and efficiency, has brought along a number of issues regarding the security of large systems [2]. The occurrence of contingencies may cause dramatic interruptions of the power supply and considerable economic damages. Such difficulties motivate the research efforts that aim to identify whether a power system is insecure and further to promptly intervene. Competition in the electric market forces generating companies as well as system operators to operate the system with lower security margins in order to remain competitive with other electricity suppliers and to allow this competition to take place over a wide region. This will result into changes in power flow patterns, increase in operational uncertainties, and reduce in security level. Since electricity is vital in today's societies power system security is remained to be one of the important aspects of power system operation which cannot be compromised in a market-driven environment.

This chapter presents a coherent definition of the problem addressed by this thesis, and describes the objectives, scopes, and major contributions of the present research.

1.2 Regulated and Deregulated Power System

Electric utilities are organizations that produce, deliver, distribute or sell electric power [1]. The corresponding functions associated with their actions are generation, transmission, distribution and retail sales. An overall electric power system is composed of generation, transmission and distribution facilities. Different countries have different power industry structures and may be either regulated or deregulated because of the economic and social differences between the countries, but the industry frameworks however, are all generally have some similar characteristics.

In a vertically integrated utility, the generation, transmission and distribution facilities are owned by that company, and it manages all the functions of producing, delivering, and selling electric power to the end users [3]. In this type of industry structure, the required revenues are directly related to the cost-of-service based on investment. One of the advantages the traditionally regulated industry has is in the coordination of all the functions required to provide a highly reliable electrical supply. One of the important disadvantages of the traditionally regulated industry is the lack of competition in the created monopoly. This creates losses in efficiency and economic incentives that are important factors in a market-based economy.

Traditional regulated industry structures have existed for a long time [1], [3]. In recent years, regulated power industry has to adapt to social, economic, political and technical changes. Competition has become the key factor driving the deregulation process in the electric power industry, and should benefit both the customers and the participating companies. The key concept behind deregulation in almost every country is that no one company should have a monopoly on either segments of the system.

There is considerable published material available on power industry deregulation all over the world over the good and bad points of deregulation [1]. One of the advantages in the newly deregulated industry is the resulting competition and the benefits that it brings to the utility companies and customers. However, one of the biggest problems associated with the deregulation process is the resulting financial risk caused by the uncertainty existing in the market.

Figure 1.1 illustrates some of the changes in the power industry due to the deregulation process. The left side of the figure shows a general industry structure before deregulation and the right side shows the basic elements existing after deregulation.

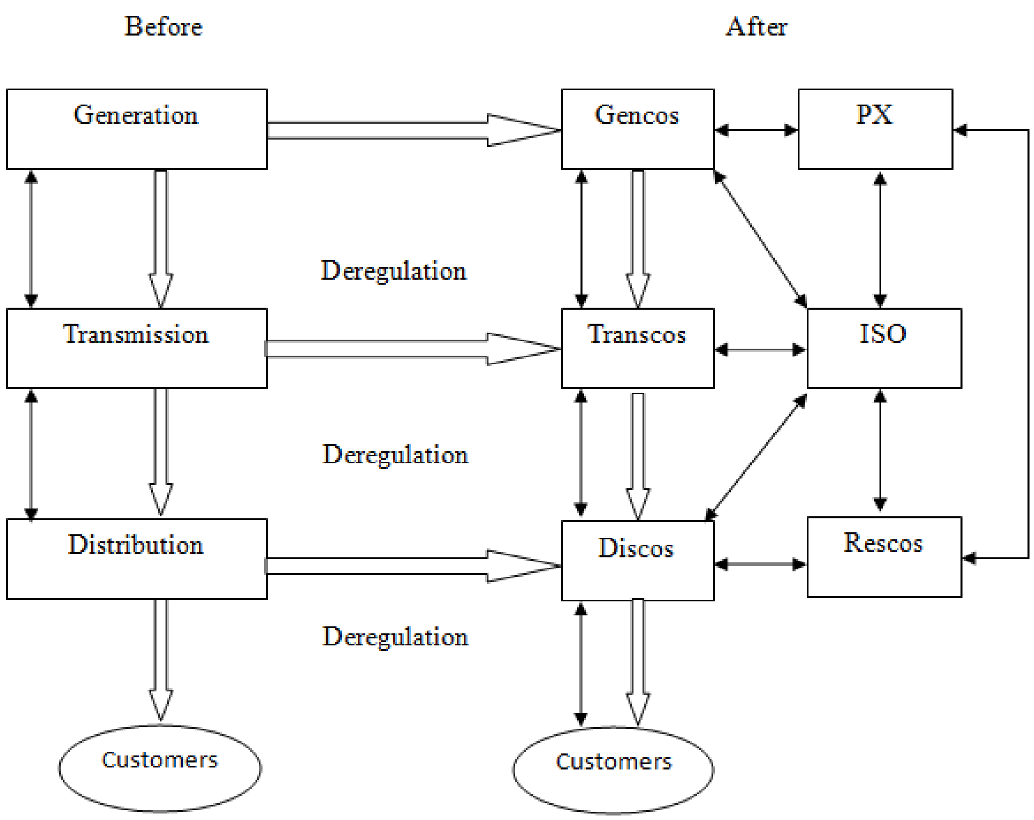

Figure 1.1: The deregulated power system

Gencos are Generation companies that own generating units and produce electric power. Transcos are Transmission companies that own transmission lines and move power in bulk quantities from generation to the distribution companies. Discos are Distribution companies that deliver electricity to the consumers. A Power Exchange (PX) is an entity that is allowed to buy and sell electric energy as a commodity. An Independent System Operator (ISO) is a non-partisan organization that oversees and ensures the operation of power system in a region in a reliable and economical manner, and provides equitable treatment to all who need to use the bulk transmission system. Finally, Rescos are Retail energy services of electric power to end customers. Gencos, Transcos, Discos, and ISO, which are independent entities in the newly deregulated industry, were integrated elements in the vertically integrated electric utilities. The PX and Rescos are companies established following deregulation exercises.

The single arrows in Figure 1.1 indicate the flow of electric power and the double arrows indicate the flow of information between the entities. As can be seen here, the power system structure before deregulation is comparatively simple. Generation, transmission and distribution are controlled by one system or company and electricity flows from generation to customers directly with the aid of information exchanged between the generation, transmission and distribution divisions. In the new deregulated environment, however, the basic functions of generation, transmission and distribution are performed by a series of new corporate utilities, viz Gencos, Transcos, Discos, PX, ISO and Rescos.

1.2.1 Models for the Power Market

In contrast to traditional utilities, where power sold was cost-based, in the deregulated power system, the sale of power is price-based [1]. Thus electric power is treated as a commodity, and traded in the market. Since it is very uneconomical, if not impossible to store bulk quantities of power, the power market is essentially a real-time market, where generation meets demand on a moment-to-moment basis. Three major market models have been proposed to facilitate efficient trading of power: the pool model, the bilateral contract model, and the hybrid model.

A pool is a centralized marketplace that clears the market for sellers and buyers who submit bids into the pool for the amounts of energy that they are willing to sell/buy. The sellers compete to inject power into the grid, and not for specific customers. Similarly buyers compete to buy power from the grid and not from specific sellers. The ISO, or a similar entity, taking into account the demand, dispatches the available generating resources, such that the demand is met at minimum cost.

The sale of power takes place at one price - the Market Clearing Price (MCP). This is the price that the sellers receive from, and the buyers pay to the PoolCo. The MCP, in most cases, is the highest winning bid. This implies that essentially, low cost producers would be benefited. While dispatching generation, the ISO ensures the security and reliability of the transmission network.

On the other hand, the bilateral contract model, also known as the Direct Access or the point to point model, involves direct contracting between the sellers and buyers (distribution companies, large industrial consumers) for trading power, in the market place, without any involvement of the system operator. The role of the ISO is thus limited in this model. After the contracts are finalized (in terms of the amount and location), the ISO is notified. The ISO ascertains die impact of the transaction on the transmission network from the point of view of network security, before deeming the transaction as feasible or infeasible.

The Hybrid model is essentially a combination of the two previous models. Customers are allowed to enter in to bilateral contracts and choose suppliers from the pool as well. Thus this enables market participants to choose between two options based on provided prices and services.

1.3 Power System Operating States and Security Concepts

The power system operates under two sets of constraints: The load and the operating constraints [4]. The load constraint is an equation constraint which sets the total generation equal to total load plus total power losses. The operating constraints are upper and/or lower limits of system's variables. The system operating states, which provide a conceptual basis for making security decisions in operational and long term planning is elaborated in Figure 1.2 can be divided into normal, alert, and emergency states for security evaluation of composite systems.

There are three basic elements of on-line security analysis and control, namely, monitoring, assessment and control. They are tied together in power system operation. Figure 1.2 graphically depicts the power system security concepts.

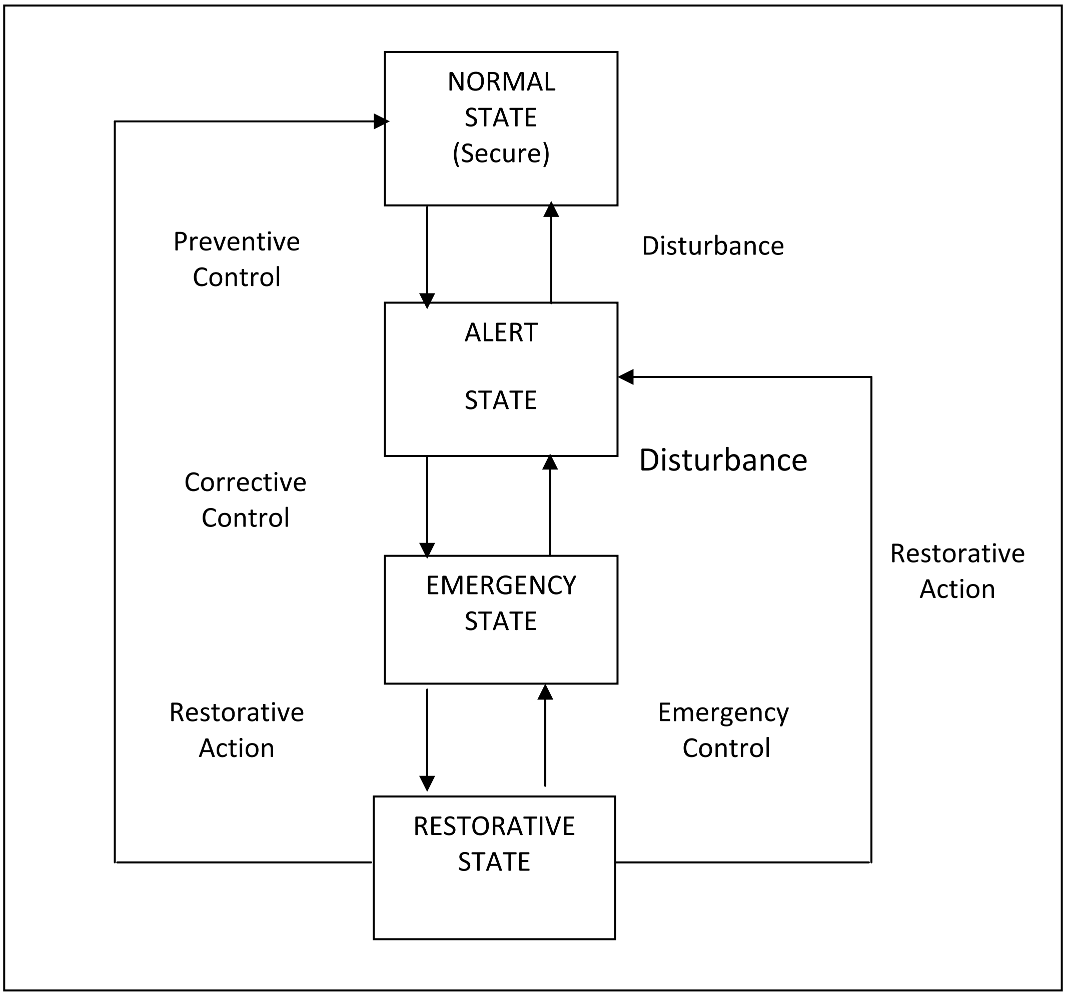

Figure 1.2: Operating States of a Power System

1.3.1 Security Monitoring

Security monitoring is the on-line measurement of system and environmental variables that affect system security; provides base case conditions for analysis of the effects of contingencies (security assessment) and to identify whether the system is in the normal state or not.

1.3.2 Security Assessment

Security assessment is the evaluation of data, provided by security monitoring, to estimate the relative robustness (security level) of the system in its present state (i.e. determination of whether the system is in the Normal or Alert operating state). While in the normal secure substate, the system can withstand any possible disturbance. If any disturbance actually occurs, the post disturbance system variables are within their pre-specified limits. If a disturbance can cause violation of operating constraints then the system is in its insecure or alert substate.

1.3.3 Security Enhancement

Security enhancement is a specific operations taken on-line to improve system robustness, ie. to raise the performance level of system security. Includes or is also referred to variously in the literature as security dispatch, security control, corrective rescheduling, preventive action, etc. If insecure, i.e. there is at least one contingency which can cause an emergency. At this substate preventive control should be applied to move the system to a normal secure state. If a disturbance that results in violations of operating constraints actually occurs, then the system is in an emergency state.

Such violations should be corrected immediately through emergency control actions to prevent further degradation of the system's operating conditions. Persisting operating constraint violations result in partial loss of load (violation of the load equality constraint). In this case, the system is in a restorative state, restorative control should be applied in a step by step procedure to move the system preferably in its normal secure state. Indeed the probability of emergency state can be expressed as the complement of the sum of these two state probabilities.

1.3.4 Power System Reliability Evaluation

The primary role of a power system is to provide reliable and continuous electrical energy to satisfy system load. Power system reliability, in a broad sense, can be defined as the ability of the system to provide an adequate supply of electric power with satisfactory quality.

The term “reliability” when used in a power system context has a very wide range of meaning [5], [6]. In order to be more specific it is usual to divide the term into the two aspects of adequacy and security, as shown in Figure 1.3.

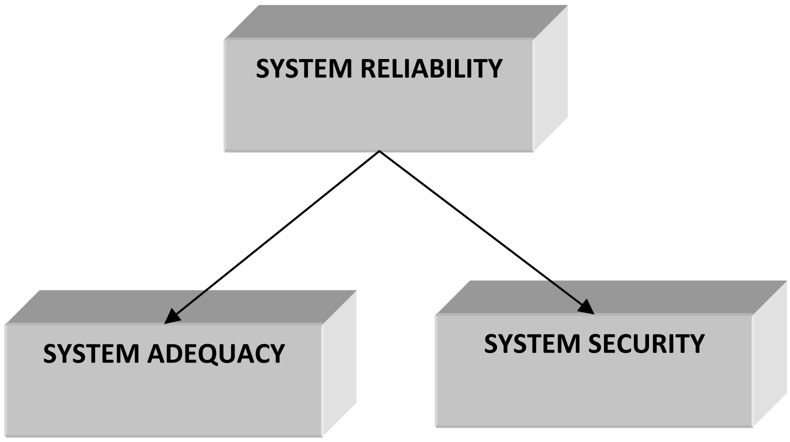

Figure 1.3: Subdivision of System Reliability

System adequacy relates to the existence of sufficient facilities within the system to satisfy the consumer load demand or system operational constraints [2]. These include the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities required to transport the energy to the actual consumer load points. System security relates to the ability of the system to respond to disturbances arising within that system. Security is therefore associated with the response of the system to whatever perturbations it is subject to. These include the conditions associated with both local and widespread disturbances and the loss of major generation and / or transmission facilities, which can cause dynamic, transient, or voltage instability of a power system.

Among the various power system functions, security remains a source of major concern. Power system deregulation and the increasing need to operate systems closer to their operating limits imply the use of more systematic approaches to security in order to maintain reliability at an acceptable level.

1.4 Power System Security Assessment

Security assessment is analysis performed to determine whether, and to what extent, a power system is “reasonably” safe from serious interference to its operation. Thus, security assessment involves the evaluation of available data to estimate the relative robustness (security level) of the system in its present state or some near-term future state. The form that such assessment takes will be a function of what types of data are available and of what underlying formulation of the security problem has been adopted.

The standard approaches to the security assessment of electrical power systems are usually classified as either static or dynamic [7]. More specifically, the static security analysis (SSA) is the post-contingent steady state evaluation of the power system by neglecting the transient behavior and any other variations that may depend on the load-generation conditions. On the contrary, if one accounts for the transition from the pre-contingent state to the post-contingent one, in the literature it is usually referred to as dynamic security analysis (DSA).

1.4.1 Dynamic Security Assessment

DSA typically covers two different aspects of the power system stability, i. e., rotor angle stability and voltage stability [8]. Transient stability is related to the ability of the system to maintain synchronism when subjected to severe disturbance, such as a short circuit of a transmission line, loss of generators/loads. It depends on both the initial operating state and the severity of disturbance. The resulting system response is affected by the nonlinear power-angle relationship.

1.4.2 Transient Stability Assessment

The objectives of Transient Stability Assessment (TSA) are to assess the transient stability of a power system subject to a set of pre-assigned contingencies, and to provide the operators with efficient control measures to assure the system transient stability while maintaining economic operation [8].

TSA has always been a challenging problem since the methodology has to be able to cope simultaneously with the modeling complexities, large dimensions of power systems, and a fast assessment of system behavior under a variety of contingencies for real-time monitoring.

1.4.3 Static Security Assessment

One of the most important studies in the planning, design, operation and control of an electric power system is the static security assessment (SSA) [9]. The operating conditions affect heavily the operating constraints are being met and there are no contingencies, which could result in a risky operating point, then the system is said to be in a secure state. If a contingency, such as a line outage can cause overloads, then the power network is said to be in a vulnerable state and the operator must take preventive actions in order to ensure that the system will remain secure.

In the new restructured scenario, it is mandatory to assess the electric power system security for a specified operating point considering a set of contingencies in an efficient and reliable manner [10]. In order to carry out this study the security analysis requires the simulation of a large number of scenarios, such as the outages of transmission lines, transformers and generating units.

1.5 Problem Statement

The SSA problem is considered as an important aspect in power system operation. The main difficulty lies in the fact that electric power systems are highly nonlinear. The solution of a nonlinear system of equations (named the load flow equations) is necessary in order to determine the power flow pattern and the voltage profile of the system. Time constrained is the main problem to solve systems of several thousand buses within a few seconds on a desktop computer. Difficulties do arise in solving the power flow equations for unusual or highly stressed operating conditions resulting in either slow, or no, convergence to a solution.

The problem is further complicated when power system is deregulated. In recent years, this deregulation of power system has turned SSA into a challenging task for which acceptably fast and accurate assessment methodology is essential. Therefore, a crucial need for faster and more accurate methods is required for SSA. It is important to reduce computation time in security assessment for on-line application involving transactions in deregulated system, since the security level of power system need to be determined as fast as possible.

Therefore, the problem being addressed by the present research work is stated as follows:-

A methodology for accurate and real time assessment of SSA in deregulated power system is required. The method must be able to handle the problem associated with SSA. It should be able to perform SSA satisfactorily in terms of accuracy and computation time. It must also be applicable for deregulated power system in various sizes and configurations.

It appears that AI -based methodology can be utilized to address the problem.

1.6 Research Objectives

The objectives of the research are as follow:

i. To examine various aspects related to security assessment concept for vertically integrated and deregulated power systems.
ii. To assess the suitability and adequacy of using existing analyses technique related to security assessment in vertically integrated system for deregulated system.
iii. To develop a benchmark techniques using Newton Raphson load flow technique for SSA.
iv. To develop SSA techniques in deregulated systems using Artificial Intelligence techniques.
v. To verify the developed techniques against the benchmark using several test systems configured as deregulated systems.

1.7 Research Scope

In order to achieve the research objectives, the scope of the study are focused on the following aspects:

i. Assessment the static security with constraints of transmission line thermal limit and bus voltage limit.
ii. Development of an algorithm using load flow analysis as benchmark for SSA in deregulated power system.
iii. Development and refining new algorithm using three Artificial Intelligence techniques, namely Artificial Neural Network (ANN), Decision Tree (DT), and Artificial Neural Fuzzy Inferences System (ANFIS) for SSA.
iv. Testing the new algorithm on standard IEEE test systems configured as deregulated power systems against the benchmark algorithm in term of accuracy, computation time.

1.8 Contributions of the Research

The contributions of the research are as follows:

i. The originality of this study is the implementation of system classification based on neuro-fuzzy system.
ii. Implementation and comparison of many types of DT which have been found to be very suitable for SSA classification of the operating state.
iii. Implementation of different methodology to reduce the computation time by reducing the large amount of the off-line simulations in the training phase.

1.9 Thesis Outline

This thesis contains five chapters and organized as follows:

Chapter 1 provides a brief introduction of the study. It covers topics on problem background and problem statement, research objectives, research scope, and thesis outline.

Chapter 2 provides the relevant background of SSA assessment and its existing techniques. Moreover, the relevant artificial intelligence techniques are presented in this chapter, and these include artificial neural networks, support vector machine (SVM) and decision Tree (DT). The literature review and analysis of current intelligent techniques related works.

Chapter 3 describes in-depth methodology used in this study. The research methodology is presented as flow chart diagram that describes how each step is carried out.

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