CHAPTER 1

INTRODUCTION

A reliable, continuous supply of electrical energy is essential part of today’s complex societies. In recent years the power systems are pushed to operate closer to their limits due to the combination of increased energy consumption and various kinds of obstructions to extension of existing transmission system. A power system is said to be secured when it is free from danger or risk. Security is ability of the system to withstand any one of the pre-selected list of contingencies without any consequences.

Conventional methods for contingency analysis involve load flow analysis which is an iterative method. Various methods like AC load flow and several performance index (PI) based methods are used for power system contingency analysis. In conventional methods a power flow solution is required at each iteration, which is again an iterative method itself. Therefore these methods are not suitable for online applications due to the large computation time. All these approaches involve a huge number of AC load flow calculations to determine the bus voltages and line flows for each contingency. It is a challenging task for today’s high speed computers and efficient algorithms. Another difficulty is that contingency analysis always uses approximate fast converging load flow algorithms such as Fast Decoupled load flow analysis which has poor convergence characteristics when dealing with heavily loaded power
systems. There are other simple techniques such as most popular DC load flow analysis. The results are acceptable when compared with standard AC load flow method; however it can only provide the Real Power (MW) flow under each contingency. Therefore voltage violations and line over loads due to excessive Reactive Power (VAr) flows cannot be detected using this method. Distribution factors and sensitivity analysis, another method based on linear model can also be used for this purpose but this method cannot provide accurate solution for a large power system due to its nonlinearity.

For security assessment purpose it is vital to reduce computational time, since the security level of power system need to be determined as quick as possible and the analysis of all credible contingencies within a very short time is needed. Artificial Neural Networks (ANNs) attracted many researchers and engineers from power system area to look for the solutions to some of complex problems to improve the speed in security level. It has been proved that these ANNs are capable of learning from raw data and they can be used to identify internal relationship within raw data not explicitly given or even known by human experts and there is no need to assume any linear relationship between data. This method is preferred because it requires no calculation based on mathematical model.

Most existing ANNs used for solving power system problems have been designed using real numbers. In power engineering applications
such as load flow, contingency analysis, phasor evaluation, signal and image processing involve complex data to be processed. However, the application of ANN method in processing of complex values is still an open problem. The easiest solution would be to consider a conventional real-valued network where the complex input and output signals are replaced by pairs of independent real-valued signals.

The rapid deregulation of electric power industry and bi-lateral power transactions between the participating areas have necessitated the urgent requirement of new methods for estimating and updating the available transfer capability (ATC). This information must be updated on the web based OASIS (Open Access Same Time Information System) for latest capacity reservations and transactions.

Electric utilities around the world are confronted with restructuring, deregulation and privatization thereby creating a wide range of impact on the present day power systems. As market participants can produce and consume energy in amounts, transmission lines are operated beyond their capacities causing congestion. Congestion management of deregulated transmission network is important to accomplish non discriminative network access. The recent restructuring of power systems has created most challenging problems with respect to operation and security. The transmission network is heavily loaded due to various factors like cost involved in constructing new transmission lines, right of way and environmental conditions. This
has a great impact on power systems by overloading the transmission lines and causing the voltage decrease at the buses and congestion. In these situations the network security can be increased by controlling power flow i.e. re-dispatching the power and reactive power injection by incorporating FACTS devices.

This chapter introduces the important concepts and includes an explanation of the most relevant work and literature survey.

1.1 CONTINGENCY ANALYSIS

Contingencies are defined as potentially harmful disturbances that occur during the steady state operation of a power system. Load flow constitutes the most important study in a power system for planning, operation and expansion. The purpose of load flow study is to compute operating conditions of the power system under steady state. These operating conditions are normally voltage magnitudes and phase angles at different buses, line flows (MW and MVar), real and reactive power supplied by the generators and power loss.

In a modern Energy Management power system security monitoring and analysis form an integral part but the real time implementation is a challenging task for the power system engineer. A power system which is operating under normal mode may face contingencies such as sudden loss of line or generator, sudden increase or decrease of power demand. These contingencies cause transmission line overloading or bus voltage violations. In electrical power systems
voltage stability is receiving special attention these days. During the past two and half decades it has become a major threat to the operation of many systems. The transfer of power through a transmission network is accompanied by voltage drops between the generation and consumption points. In normal operating conditions, these drops are of the order of few percents of the nominal voltage. One of the principle tasks of power system operators is to check that under different operating conditions and/or following credible contingencies (e.g.: tripping of a single line) all bus voltages remain within bounds. In such circumstances, however in the seconds or minutes following a disturbance, voltages may experience large progressive falls, which are so prominent that the system integrity is endangered and power cannot be delivered to the customers. This catastrophe is referred to as voltage instability and its calamitous result as a voltage collapse.

Large violations in transmission line flow can result in line outage which may lead to cascading effect of outages and cause over load on the other lines. If such over load results from a line outage there is an immediate need for the control action to be initiated for line over load alleviation. Therefore contingency analysis is one of the most important tasks to be met by the power system planners and operation engineers. But on line contingency analysis is difficult because of the conflict between the accuracy in solution of the power system problem and the speed required to simulate all the contingencies. The simulation of
contingency is complex since it results in change in configuration of the system.

1.1.1 METHODS OF CONTINGENCY ANALYSIS

The different methods used for analyzing the contingencies are based on full AC load flow analysis or reduced load flow or sensitivity factors. But these methods need large computational time and are not suitable for on line applications in large power systems. It is difficult to implement on line contingency analysis using conventional methods because of the conflict between the faster solution and the accuracy of the solution. Some important methods are

1. AC load flow methods
2. DC load flow method.
4. Performance Index method.

1.1.2 LOAD FLOW METHODS

The objective of power flow study is to determine the voltage and its angle at each bus, real and reactive power flow in each line and line losses in the power system for specified bus or terminal conditions. Power flow studies are conducted for the purpose of planning (viz. short, medium and long range planning), operation and control. The other purpose of the study is to compute steady state operating point of the power system, that is voltage magnitudes and phase angles at the buses. By knowing these quantities, the other quantities like line flow (MW and
MVAR), real and reactive power supplied by the generators and loading of the transformers can also be calculated. The conditions of over loads and under or over voltages existing in the parts of the system can also be detected from this study.

The need of power flow study is summarized as follows:

- By performing this study over loaded as well as poor voltages existing in parts of the system can be detected.
- Load flow study is performed by the planning engineer for different configurations and load conditions before deciding on a final configuration.
- For accurate contingency evaluation purpose load flow analysis is an important tool to simulate various equipment outages.
- In a deregulated energy market this analysis is used to determine the available transfer capability.
- Another interesting application is in finding optimal location of capacitors and their size in a transmission line to improve voltage profile, compensate reactive power and to enhance transfer capability.

The different mathematical techniques [1, 2, 3] used for load flow study are

1. Gauss Seidel Method
2. Newton Raphson Method
3. Decoupled method.
4. Stott’s fast decoupled method.

1.2 TRANSFER CAPABILITY CONCEPTS

For secured and economic supply of electric power, long distance bulk power transfers are essential, but the power transfer capability of a power system is limited. To operate the power systems safely and to gain the advantages of bulk power transfers, computations of transfer capability is essential. Transfer capability plays a vital role in liberalized electricity market. All the transmission lines are utilized significantly below their physical limits due to various constraints. By increasing the transfer capability the economic value of transmission lines can be improved and also there will be an increase in overall efficiency as more energy trading can take place between the competing regions with different price structures. The power system should be planned and operated such that these power transfers are within the limits of the system transfer capability. Transfer capability of a power system is defined as the maximum power that can be transferred from one area to another area.

1.2.1 NEED FOR TRANSFER CAPABILITY COMPUTATION

Transfer capability plays an important role in bi-lateral energy market. It indicates the amount of power that can be transferred on a transmission network between the two interconnected areas. Computation of transfer capability is essential and useful for several
reasons. The need for transfer capability computation is summarized as follows:

1. A system is said to be more flexible and robust if it can accommodate large inter area power transfers compared to one with limited capacity. Thus transfer capability indicates the relative system security.

2. Transfer capability is useful in power system planning and designing. The relative merits of the planned improvements in transmission networks can be obtained from these computations.

3. To appropriate the effects of multi area commerce or transactions and to furnish the details of the inexpensive power likely to be available to insufficient generation or high cost regions, transfer capability can be used as an alternate in specific circuit modeling.

4. In energy market applications it can be used to evaluate the transmission reservations.

### 1.2.2 TRANSFER CAPABILITY AND POWER SYSTEM SECURITY

Computation of Transfer Capability plays a vital role in power system planning and secured operation. To increase the reliability power systems are interconnected to form a grid. In such systems the loss of generation in one part can be substituted by the generation from the other part or area. This is an added advantage of the interconnected
system compared to individual power system as it can survive such contingencies. In estimating the ability of the interconnected power system to remain secure during the unexpected contingencies like line outages and generator outages, computation of transfer capability is essential.

**1.2.3 TRANSFER CAPABILITY AND ELECTRICITY MARKET**

In the present deregulated environment with multiple power transactions computation of transfer capability emerges as the key issue to run the energy market smoothly. Total transfer capability forms the basis for the determination of Available Transfer Capability (ATC) which is the indication of the amount of inter area power transfer that can be increased without system security violations. The concept of deregulation rather than monopoly has become prominent to promote healthy competition between the sellers and to drive down the cost of energy. This has also initiated to accomplish reliable operation with better service at most competitive price.

The first country to initiate the deregulation of power industry is United Kingdom followed by Australia and Norway. The Federal Energy Regulatory Commission (FERC) in conjunction with North American Electric Reliability Council (NERC) approved the posting of ATC information through internet based Open Access Same Time Information System (OASIS) for the use of energy market participants. This information is important as it reflects the system realistic conditions
such as demand levels of the customers, network paradigm, and generation dispatch and inter-area transfers.

1.3 FLEXIBLE AC TRANSMISSION SYSTEMS (FACTS)

The static and dynamic limits of transmission system restricted the power system transactions leading to underutilization of existing transmission lines. Previously traditional devices like fixed shunt, series reactors and capacitors were used to alleviate this problem however slow response; mechanical wear and tear confined their usage. The greater need for more efficient system has given rise to the development of alternative technology made of solid state, fast response devices. The other reasons like recent restructuring of power systems, difficulty in construction of new transmission lines and modified environmental and efficiency regulations have further fuelled the need for such devices. The invention of semiconductor devices like SCR opened the doors to the development of FACTS controllers.

Flexible Alternating Current Transmission Systems are used for control of voltage, phase angle and impedance of high voltage transmission lines. The strategic benefits of incorporating FACTS devices are improved reliability, better utilization of existing transmission system, improved availability, increased transient and dynamic stability and increased quality of supply. Due to dynamic nature of load and generation patterns, heavier line flows and higher losses are occurred causing security and stability problems. To overcome these problems in
the present deregulated scenario more sophisticated control using FACTS devices is essential.

According to IEEE definition FACTS devices are power electronic base or other static controllers incorporated in AC transmission systems to enhance controllability and increase power transfer capability.

1.3.1 TYPES OF FACTS CONTROLLERS

FACTS controllers are classified as series controllers, shunt controllers, combined series–series controllers and combined series–shunt controllers.

i) SERIES CONTROLLERS

These devices are connected in series with the lines to control the reactive and capacitive impedance there by controlling or damping various oscillations in a power system. The effect of these controllers is equivalent to injecting voltage phasor in series with the line to produce or absorb reactive power. Examples are Static Synchronous Series Compensator (SSSC), Thyristor controlled Series Capacitor (TCSC), Thyristor-Controlled Series Reactor (TCSR). They can be effectively used to control current and power flow in the system and to damp system’s oscillations.

ii) SHUNT CONTROLLERS

Shunt controllers inject current in to the system at the point of connection. The reactive power injected can be varied by varying the
phase of the current. The examples are Static Synchronous Generator (SSG), Static VAR Compensator (SVC).

### iii) COMBINED SERIES-SERIES CONTROLLERS

This controller may have two configurations consisting of series controllers in a coordinated manner in a transmission system with multi lines or an independent reactive power controller for each line of a multi line system. An example of this type of controller is the Interline Power Flow Controller (IPFC), which helps in balancing both the real and reactive power flows on the lines.

### iv) COMBINED SERIES-SHUNT CONTROLLERS

In this type of controller there are two unified controllers a shunt controller to inject current in to the system and a series controller to inject series voltage. Examples of such controllers are UPFC and Thyristor- Controlled Phase-Shifting Transformer (TCPST).

### 1.3.2 OPTIMAL PLACEMENT OF FACTS DEVICES

The main considerations for incorporating the FACTS devices in power transmission system are improvement of system dynamic behavior, reliability and control of power. For the location of FACTS controller one of the following objectives may be chosen:

1. To reduce real power loss of a line.

2. To reduce Total real power loss of a system.

3. To reduce the total reactive power loss of the system.

4. To alleviate congestion by controlling power flow.
Sensitivity factors can be used for the first three objectives. To alleviate congestion and to improve transfer capability trial error methods can be used.

1.4 ARTIFICIAL NEURAL NETWORKS

Artificial Neural Network is an information processing paradigm inspired by the functionality of human brain. Its ability to perform computations is based on the hope to reproduce the enormous power and flexibility of the human brain to some extent. Artificial neural networks are composed by large number of highly interconnected processing elements called artificial neurons or simply neurons or nodes. Theses neurons operate collectively and simultaneously to solve specific problems. The two functions that are performed by theses neurons are summing and nonlinear mapping. The neurons are organized in layers and they operate in parallel. Feedback connections between the layers and within the layers are used. The strength of each connection is expressed by a numerical value called weight which is adjusted during the learning process. These weights encode the knowledge. Architecture of the network is the basic characteristic of ANN and the response depends on the time domain behavior.

1.4.1 ADVANTAGES OF ARTIFICIAL NEURAL NETWORKS

Artificial neural networks have the ability to draw logical consequence from the complex or raw data and can be used for classification of patterns, trends that are complex to be noticed by either
human eye or other computer techniques. Conventional computers are to be programmed to perform specific task where as ANNs are to be trained or taught first to learn new patterns, association and functional dependencies. Learning of knowledge acquisition of a neural network corresponds to parameter changes. Once the network is trained it can be considered as an expert who can provide the solution or projections to a given situation.

The advantages are:

1. Adaptive learning
2. Self organization.
3. Real time operation
4. Robust and fault tolerance.
5. Superior noise cancellation capability.

1.4.2 BIOLOGICAL NEURAL NETWORK VERSUS ARTIFICIAL NEURAL NETWORK

A biological neural network is a network of a large number of special cells in the body called ‘neurons’, each of which is capable of receiving and transmitting electrical signals of varying strengths in order to transfer sensory information to the brain as shown in Figure 1.1.
Artificial neural networks are highly simplified models of the aforesaid structure. It has much large number of simple neuron-like processing elements called nodes which are parallel. The neurons or nodes of different layers are interconnected with large number of weighted connections between the elements as shown in Figure 1.2. These weights encode the knowledge.

Fig. 1.1 Biological Neuron

Fig. 1.2 Artificial neuron model
1.4.3 BASIC NEURON MODEL

The fundamental unit or building block of an artificial neural network is called neuron or processing element which is also called artificial neuron.

A general neuron shown in Figure 1.3 has a set of n inputs $x_i$, where the subscript takes values from one to n. Each input is weighted before reaching the main body of the processing element by the connection strength or weight factor $w_j$. In addition it has a bias value $\Theta$, which has to be exceeded for the neuron to produce a signal or activation ‘$R$’ and an output ‘$O$’ after the nonlinearity function: ‘$O$’ constitutes input to the other neuron. A neuron is referred as a node when it is a part of a network of large number of neurons.

![Fig. 1.3 Basic Neuron Model](image)

The transfer function of the basic model is given by

$$O_i = F_i \left( \sum_{j=1}^{n} w_{ij} x_j + \Theta \right)$$  \hspace{1cm} (1.1)
The neuron’s firing condition is

$$\sum_{j=1}^{n} w_{ij} x_j \geq \Theta_i$$  \hspace{1cm} (1.2)

The purpose of nonlinearity is to ensure that the neuron’s response is bounded, that is the actual response of the neuron is conditioned, or damped as a result of large or small activating stimuli and thus is controllable.

The two most popular nonlinearities are the hard limiter and sigmoid functions.

**Fig. 1.4 Hard limiter**

**Hard limiter or sign function**

$$\text{sign}(x) = +1, \text{ if } x \geq 0$$

$$-1, \text{ if } x < 0$$

**Fig. 1.5 Sigmoid**

**Sigmoid function**

$$g(x) = \frac{1}{1 + e^{-x}}$$  \hspace{1cm} (1.3)

for a bipolar sigmoid function

$$g(x) = \frac{2}{1 + e^{-x}} - 1$$  \hspace{1cm} (1.4)
1.4.4 TYPICAL ANN ARCHITECTURES

Neurons are arranged in layers and typically the neurons in the same layer behave in the same manner. The behavior of the neuron depends on the activation and the pattern of the weighted connections over which it receives signals. The arrangement of neurons in different layers and the patterns within and between layers is known as architecture.

1.4.5 SINGLE LAYER NETWORK

A single layer neural network has one layer of connection weights. It has one input layer which receives the signals and a layer consisting of output nodes. The Hopfield Net is an example of single layer net. For pattern classification and pattern association this type of network can be used.

1.4.6 MULTILAYER NETWORK

Multilayer perceptron is an important class of neural networks and are widely applied to the problems of classification, function estimation.

In a multiplayer perceptron there are three layers namely input layer which is a group of input nodes, output layer a group of output nodes and in between a hidden layer which consists of processing neurons. A typical representation of multiplayer perceptron is shown in Fig.1.6. The multi layer perpeptrons are trained in a supervised manner by applying the error back propagation algorithm.
1.4.7 LEARNING

Learning is the process by which the neural network adapts itself to a stimulus and eventually it produces desired output after making the proper parameter adjustments to itself. It is a continuous classification process of input stimuli; when a stimulus appears at the input nodes of a network it either recognizes it or it develops a new classification. During the process of learning the synaptic weights are adjusted in response to the input so that its actual output response converges to the desired or target output response. When the actual output response is same as the desired response then the network is said to be learned or acquired knowledge. There are different learning methods and each learning method is described by a set of equations.
1.4.8 SUPERVISED LEARNING

Training or learning of a neural network is accomplished by presenting a sequence of training vectors or samples or patterns each with an associated target output vector. The weights are adjusted according to the learning algorithm. This process is known as supervised learning. Fig. 1.7 represents supervised learning process.

![Supervised Learning Diagram]

Fig. 1.7 Supervised learning

1.4.9 UNSUPERVISED TRAINING

In an unsupervised training a sequence of input vectors is provided but no target vectors are specified. The net modifies the weights so that most similar input vectors are assigned to the same output unit or cluster unit. It arbitrarily organizes the patterns into categories. Even though unsupervised learning does not require a teacher or target output it requires guidelines to determine formation of clusters. Its representation is shown in Fig. 1.8.
1.4.10 DELTA LEARNING ALGORITHM

The Delta rule is based on the idea of continuous adjustments of the value of the weights such that the difference of error (delta) between the target value and the actual output value of a processing element is minimized. It is also known as Widrow-Hoff learning rule or as LMS (Least Mean Square) error.

The least squared error $E$ between the target output $T$ and the actual output $O$ is defined by

$$ E = \frac{1}{2} (T_i - O_i)^2 = \frac{1}{2} [T_i - f(w_i x_i)]^2 $$

(1.5)

Where $w_i$ is the matrix representation of weights; $x_i$, $O_i$, $T_i$ are the vector representations of the input, actual output and target output respectively of the $i^{th}$ neuron and $f$ is the activation function.

The error gradient vector is

$$ \nabla E = -(T_i - O_i) f'(w_i x_i) x_i $$

(1.6)

for minimization of error negative sign is used.
For minimization of error the weight changes should be in the negative gradient direction. Therefore we take

$$\Delta w_i = -\eta \nabla E$$

where $\eta$ is a positive constant.

### 1.4.11 APPLICATION OF ANNS TO POWER SYSTEMS

The Key attributes for the application of Artificial Neural Networks to power system are listed below are listed below:

- Power system may need to be repeatedly solved in the hour to hour operation and control of power systems. The frequency of solution depends on the operational sophistication of the particular utility.

- Conventional solution techniques may be computationally intensive and time consuming. They may use up excessive time on the Energy Management System (EMS) computers resulting in high computational cost.

- Explicit mathematical modeling may not be feasible due either to the complexity or the lack of available information regarding the problem.

- Available knowledge may not be in a functional form, but rather in the form of historical input/output examples.

- Operating conditions could be noisy.
1.5 COMPLEX VALUED NEURAL NETWORKS

The previous section 1.4 describes the conventional Artificial Neural Networks. These ANNs are built upon the real number environment i.e. input, weights and output are all in real form. However the computations related to power systems load flow analysis, contingency analysis most of the equations having complex variables are extensively involved. The admittances, voltages, line flows are all expressed in complex form. Hence ANNs using complex neurons and weights must be adopted for such applications although conventional ANNs can be used for complex numbers by splitting them in to real numbers which represent real and imaginary parts.

Complex valued neural networks (CVNN) deal with complex valued data with complex number weights and activation functions. When the synaptic weights are multiplied by the complex input data presented at the input layer the multiplication of operator ‘i’ converts the real part into imaginary one and also imaginary one to real one with negative sign and in this way the two quantities are exchanged. In a complex valued neural network when parallel input data elements are multiplied with weights the result is an output with certain relationship in complex plane. The main results obtained by using complex valued neural networks are summarized as follows
• Decision boundary of a single complex valued neuron consists of two hyper surfaces which intersect orthogonally and divide a decision region into four equal sections.
• It improves generalization ability.
• The average learning speed of complex back propagation algorithm is several times faster than that of real back propagation algorithm.

1.5.1 STRUCTURE OF COMPLEX VALUED NEURAL NETWORK

Fig. 1.9 shows the newly proposed ANN for complex numbers. The input, the weight and the output are complex numbers. The operation of complex neuron is similar to that of the conventional neuron but weight up gradation rules cannot be applied here as it has both real and imaginary parts. Therefore during training pass the real and imaginary parts are adjusted separately using the gradient function. Sigmoid function used as activation function and the output of $k^{th}$ neuron is given by Eqn. 1.8.

$$o_k = \frac{1}{1 + e^{-(w_x+ jw_y)(x+ jw)}}$$  (1.8)

The difference between the target output and the actual output gives the error and the mean squared error is calculated from the following equation.
\[ \| E \|^2 = \frac{1}{2} \sum_{k=1}^{L} \left[ (o_{vk} - d_{vk})^2 + (o_{vk} - d_{vk})^2 \right] \]  

(1.9)

**Fig. 1.9 Structure of complex valued ANN**

1.6 LITERATURE SURVEY

In this section a brief review of literature which is helpful in understanding the work presented is given. The references given are pertinent to the thesis. Many text books in the field of electrical power engineering were useful while the books on Artificial Neural networks, Complex Valued Artificial Neural Networks were particularly useful for computation purpose. MATLAB, Power World and Matpower software have been used for the analysis, simulation and validation of the proposed methods in this thesis.
1.6.1 LITERATURE SURVEY ON LOAD FLOW STUDIES

During last three decades, various methods of numerical analysis for solving a set of non-linear algebraic equations have been applied in solving load flow analysis problems [1-7]. The desirable features to compare the different power flow methods can be the speed of solution, memory storage requirement, and accuracy of solution and the reliability of convergence depending on a given situation. Though, robustness or reliability of convergence of the method is required for all types of applications the speed of solution is more important for on-line applications compared to the offline studies. Steady state of power systems may be determined by solving the power flow equations that mathematically are represented by a set of non-linear algebraic equations. That problem is known as the load-flow or Power Flow problem and its main objective is the calculation of all bus voltages magnitudes and angles, and consequently the power flows over the transmission lines [3]. Continuous growth and complexity of power systems have originated the adoption of sophisticated computer tools for efficient planning, operation and control of their systems. Power flow computer programs are used basically to calculate the steady state of practical power systems composed of hundreds or thousands of bus bars and transmission lines [2]. The history, applications and advantages using artificial neural networks in protecting power systems are summarized in several survey and tutorial papers [9-20]. R. C. Bansal
[10] presented a review on application of Artificial Neural Networks to solve various problems. It gives a detailed study on the papers published and the work done in this area.

Application of Artificial neural networks (ANNs) have shown great promise in solving power system engineering problems due to their ability to synthesize complex mappings accurately and rapidly. Most of the published work in this area utilizes multi-layer perceptron (MLP) model based on back propagation (BP) algorithm, which usually suffers from local minima and over fitting problems [15][17]. In reference [18], a neural network load flow using an ANN-based minimization model is proposed. A separate MLP model based on Levenberg-Marquardt second order training method has been used for computation for bus voltage magnitude and for angle at each bus of power system in [15]. As the number of neural networks required to solve power flow problem are large, it may not be applicable to a practical power system having huge number of buses. In reference [19], the use of artificial neural networks (ANN) is proposed for solving the well known power flow (PF) problem of electric power systems (EPS) by V. Leonardo Paucar Macros J Rider. The proposed ANN methodology has been successfully tested using the IEEE-30 bus system. In reference [20], a counter propagation neural network (CPNN) is proposed to solve power flow problem under different loading/contingency conditions for computing bus voltage magnitudes and angles of the power system. The counter propagation network uses a
different mapping strategy namely counter propagation and provides a practical approach for implementing a pattern mapping task, since learning is fast in this network. In reference [21], Radial Basis Function Neural Network is used to predict the static voltage stability index and rank the critical line outage contingencies. To speed up the learning process three distinct feature extraction algorithms are proposed for reducing the size of input training vectors. The effectiveness of the proposed algorithms for online voltage stability index prediction and contingency ranking is demonstrated by considering IEEE – 30 bus system.

1.6.2 LITERATURE SURVEY ON CONTINGENCY ANALYSIS

In power system operation and planning, security assessment is one of the key issues. It enables the power system engineer to detect through simulation, whether there are any potential line flow or voltage violations. A. J Wood, B F Wollenberg [4] described the estimation of the effects of contingencies on line power or current limits using DC load flow models and large signal sensitivities obtained from network theorems [3]. The most straightforward simulation method is to run AC power flow using the iterative algorithm for each contingency [4][8]. Although it provides accurate power flow solutions, this procedure, which involves a huge number of AC load flow calculations, is extremely costly from the computational point of view. Some approximate load flow algorithms, such as DC load flow [4], Fast Decoupled load flow [2], and
linear approximate load flow [23], are also developed to solve contingencies with less computational burden. In reference [24] Pai et al described a fast algorithm for on-line load flow and contingency evaluation. This method is based on the elimination of load nodes and the successive approximation technique, and is quite efficient but slow compared with fast-decoupled load flow method. Linear methods for contingency analysis have been in use for many years [25-28]. They remain the primary tool for estimating the impact of an outage in many security analysis programs. Despite their long history, their capabilities have not been fully exploited in several key applications. The sensitivity based ranking methods are explained in references [29][30] and screening methods are described in references [31][32]. Since the 1990s, extensive research work has been carried out on the application of neural networks to power system problems [33]. Vankayala and N.D.Rao [34] developed a method based on a coupled scheme called Artificial Neural network (ANN) based contingency screening with Expert System for PS security enhancement. In Reference [35] Lo, K. L., Peng et al. presented a fast real power contingency ranking method that has been developed as a pattern recognition problem for which a Counter Propagation Neural Network is used. It also employed feature selection for reducing the dimensionality of the input patterns. Sobajic and Pao [36] have proposed a rule-based contingency screening for both single and multiple-line outages. Artificial neural networks (ANN) have been proposed for static
and dynamic voltage security/stability evaluation [39-52] as they have the ability to produce the value of the severity indices accurately and almost instantaneously. References [39-44] employ multi-layer perceptron networks trained by back-propagation (BP) algorithm. In Reference [45] Y. H. Song, H. B. Wan and A. T. Johns applied Kohonen’s self-organizing feature to determine the bus voltages and to identify weak areas. In Ref. [48] a hybrid ANN, combining supervised and unsupervised neural network was proposed by the same authors for determining voltage stability margin as well as weak areas. Lo et al [46] proposed a counter propagation neural network (CNN) for real power contingency ranking. Srivastava, et al [47] proposed a hybrid neural network for quantifying and analyzing voltage security problems. A fuzzy version of multi-layer neural network was proposed [49] for ranking of voltage contingencies. Rafaee, et al [50] proposed a radial basis function (RBF) neural network for contingency analysis in planning studies. Two Neural Networks are used to solve this problem; line flows and bus voltage magnitude to produce better generalization results. Bus admittance matrix is used to map the line flows and bus voltages in this method. In Reference [51] Devaraj et al described the application of radial basis neural networks to capture the non-linear relationship between the pre-contingency system state and the post contingency severity level following a contingency. Ray D et al [52] presented the application of ANN for power system security analysis using feed forward neural networks.
1.6.3 LITERATURE REVIEW ON AVAILABLE TRANSFER CAPABILITY

The deregulation of the power market has imposed great impact on the utility industry. At the beginning of the new environment, new technologies and computation methods are urgently needed to smooth out the transition from the regulated market to the new deregulated market. At the top of the list is a fast algorithm to calculate the available transfer capability (ATC) [79]. The maximum power that can be transferred in a reliable fashion over any transmission line is called the transfer capability [80], as defined by NERC (North American Electric Reliability Council) [82]. In reality, the transmission transfer capability is limited by a number of various mechanisms, including stability, voltage and thermal constraints [81]. Since the need of a fast ATC calculation method appears only after the industry started deregulation recently, there are not many fast ATC calculation algorithms available today [83]. The ATC concept is similar to NERC’s incremental transfer capability [64], alternatively, a detailed AC power system model can be used throughout and the transfer margin can be determined by successive AC load flow calculations [67] or continuation methods [65-67]. Continuation Power Flow (CPF) is first introduced for determining the maximum loadability; however, it is adaptable for other applications including ATC computation without changing its principle. The advantage of CPF is that it will not encounter numerical difficulties of ill conditioned power flow equations, thus CPF yields solutions even at
voltage collapse points [85][86]. Earlier use of CPF in determining ATC [84] reveals that the complexity and computational time increases when the contingency analyses are introduced for all possible cases. Consequently, as such it is not suitable for on-line applications in its present form. A. B. Khairuddin et al presented a novel method for computing ATC [87]. In reference [88] Mohamed Shaban et al presented the calculation of TTC through optimal power flow approach in which the objective functions was to maximize the sum of the sending end generation and receiving load of specified buses.

In reference [89] Ronghai Wang, Robert H proposed a method using a distance to margin prediction formula. For cases of line flow limits, this method rapidly determines the loadability limit of the system with respect to any limit without the need for a much slower continuation step. A key concept behind this paper is that it is possible to combine ATC determination with contingency analysis in a manner that is efficient. Linearized equations to establish the effect of contingencies on both the base case flows and the linearization formula itself are proposed.

In Reference [91] Ying Yi Hong discussed a method of using multi layered feed forward network for estimation of ATC. In this paper, the principle component analysis network is used for independent system operator (ISO) to extract the essential bus information. This treatment is
used reduce the input neural node number and the training time for the neural network.

In Reference [92] K. Selvi et al proposed application of genetic algorithm to solve total transfer capability. The main objective function in this paper is to maximize a specific point-to-point power transaction without system constraint violations and determine the TTC between the two points through global optimal search.

The application of Optimal Power Flow (OPF) in power system congestion management has been studied by some researchers [69][70][71][72]. In the mean time, TTC calculation by OPF approach has been proposed since 1999 [73][74][75]. Repeated power flow method was proposed in reference [76] to explore its computational advantage. This approach starts from a base case, and repeatedly solves the power flow equations each time increasing the power transfer by a small increment until an operation limit is reached. The advantage of this approach is its simple implementation and the ease to take security constraints into consideration.

The transfer capability estimation method proposed by X. Luo et. al. [77] uses a Multi Layered Feed Forward Neural Networks which is capable of reflecting variations in load levels and in the status of generation and transmission lines. The transfer capability was estimated accurately of between system areas with variations in load levels, in the
status of generation, and in the status of lines. In this work Quick prop algorithm is used to train the neural network.

1.6.4 LITERATURE REVIEW ON NEURAL NETWORKS AND COMPLEX VALUED NEURAL NETWORKS

A number of text books on Artificial Neural networks were useful for the work presented and the derivations discussed in this thesis [122-125]. For Complex Valued Neural Network Reference [54] is referred. In recent years, there has been increasing interest in complex valued neural networks. It was realized by one of researchers, N.N Aizenberg that the basic model of a neuron must be modified to account for complex valued inputs, complex valued synaptic weights and thresholds [53]. In many real world applications, complex valued input signals need to be processed by neural networks with complex synaptic weights [54]. In reference [55] the results on real valued associative memories are extended to complex valued neural networks. In references [56][57], the celebrated back propagation algorithm is generalized to complex valued neural networks. Anitha S. Gangal et al [58] tried to evaluate and compare the performance of complex valued neural networks using different error functions. Complex version of back propagation algorithm made its first appearance when Widrow, Mc Cool and Ball [59] announced their complex least mean square (LMS) algorithm. Kim and Guest [60] published a complex valued learning algorithm for signal processing
application. Benvenuto and Piazza [61] published a different version of complex valued back propagation algorithm by using different activation functions. Most of the applications of complex valued neural networks are related to signal and image processing.

L. Chan et al [62] proposed complex neural network in 1996. The first application of complex valued neural networks to power system load flow analysis problem was proposed by the same authors [63] in 2000. In this a six bus system is used to show the merits of incorporating complex valued neural networks in power system load flow analysis.

1.6.5 LITERATURE SURVEY ON CONGESTION MANAGEMENT AND LOCATION OF FACTS DEVICES

In Reference [94] K R Padiyar and A. M Kulkarni presented the review of progress in FACTS with a generalized description of FACTS controllers. Various technologies [93][95][96] have been presented representing possible solutions to a variety of issues faces by the power industry. The economic viability of technologies is also presented. Claudio A. Canizares [90] discussed the effects of SVC and TCSC controllers on Available transfer capability using standard voltage collapse techniques. In the work presented, the effect of SVC and TCSC controllers on ATC is concentrated. Standard voltage collapse techniques are used to determine the ATC of a test system considering a variety of system limits. Sensitivity analysis is used for optimal location of these devices. In Reference [97] P. K. Dash, S. Mishra and G. Panda presented
the design of Radial Basis Function Neural Network (RBFNN) controllers for UPFC to improve the transient stability performance of power system. The active and reactive power and voltage deviations are used in this controller for the control of UPFC parameters. In Reference [98] Abbas Taher, Hadi Besharat proposed a method to find the optimal location of FACTS device (TCSC) based on an index called real power performance index and the other objective to reduce of total system reactive power loss. The optimum location is found based on minimizing production cost and device cost. Xiao-ping Zhang and Edmund Handscin [99] established mathematical model for FACTS controllers and a non linear optimization framework is proposed. In [100] Paola Pezzini et al discussed Genetic Algorithm approach for the allocation of FACTS devices for the improvement of energy efficiency in a distribution system. The variation of efficiency with the node chosen is computed using random function. In Reference [101] R. Mohamed Idreis, A. Khairuddin and M.W. Mustafa proposed Bees Algorithm for the enhancement ATC with optimal location of FACTS devices. This algorithm searches the FACTS location, Facts parameters and FACTS types. This method is compared with Genetic Algorithm method and found to be effective in finding the optimal location. But this method requires computation of fitness process for each site visited by a bee calculating by calculating ATC. P. R. Sharma, Asok Kumar, Narendra Kumar [102] have presented the effect of location of shunt FACTS device for an actual line model of a transmission line
having series compensation at the centre. It is found that the degree of series compensation affects the location of the FACTS device in this paper. In reference [103] Rajesh Rajaraman et al. presented the display between generation dispatch choices and the effect of series compensation devices on the transfer capability of the power system. Sensitivity approach [108] with an objective of reducing line loss has been suggested for the optimal placement of series compensation, phase shifters and static reactive power (VAr) compensators. In [109][110] optimization with different objective functions is discussed for optimal power flow with FACTS devices. In [113][114], economic dispatch problem including cost of the FACTS devices is solved to obtain the optimal locations of FACTS devices. In this method it is assumed that initially these devices are included in all the lines. In a vertically integrated power system several methods can be used for determining the optimal location of the FACTS devices. In Reference [108] for location of series capacitors and SVCs loss sensitivity based approach is proposed. In reference [103] Continuation Power flow method is used to determine the size and location of the series compensator to increase the power transfer capability. In reference [115] performance index is used which incorporates two factors sensitivity matrix of TCSC with respect to congested line and shadow pricing corresponding to the congested line for optimal location of TCSC for reducing congestion cost. Genetic algorithm based approach is presented in Reference [100] for the optimal
location of the devices in a distribution system. In [116] particle swarm optimization algorithm is used to determine the optimal location of various FACTS devices in a power system in order to relieve the lines from over loads. In ref [118] a sensitivity factor based approach for the optimal placement of the TCSC to minimize the congestion cost is presented. The sensitivity factor is based on the ratio of change in real power flow to the base case power flow in the most congested line.

In Reference [126] Judith Cardell discussed the use of a closed loop price signal that integrates FACTS devices in to reduce the transmission congestion in real time. Various software and tools [119-121] are used for programming and simulation purpose in this thesis.

1.7 CONCLUSIONS

In this chapter recent developments in applications of neural networks to obtain solution for problems such as power system security, operation, computation of Transfer capability and determination of location of FACTS device for the enhancement of transfer capability, that are relevant to work reported by several authors are presented. A considerable progress has been achieved in artificial neural networks applications to provide solution to power system problems. Load flow analysis forms the basis for contingency analysis and ranking. The work reported by various authors on load flow studies, contingency analysis is discussed in literature survey. Application of complex valued neural networks approach is also discussed.
Electrical utilities around the world are confronted with restructuring, deregulation. In this present open access system transmission line networks tend to be more heavily loaded and they become most critical elements. The ability to transfer power can be determined by transfer capability of the line which also indicates the strength of the power system. Various methods to compute Available Transfer Capability is reviewed in this chapter.

The overview of FACTS devices and applications in transfer capability enhancement have been reviewed in literature survey. Series compensation devices modeling and its incorporation in transmission system to reduce reactive power loss is reviewed. The work reported by authors suggests that FACTS controllers in a deregulated electricity market allow the system to be used in a more flexible way with increased stability margins. FACTS devices allow the industries to better utilize the existing transmission and generation reserve while enhancing the power system performance.