ABSTRACT

Modern power systems are large complex systems and widely distributed geographically. It operates under much stressed conditions, closer to operating limits, owing to increased demands. The changes in power systems such as; increase in loading, generator reaching reactive power limits, action of tap changing transformers, load recovery dynamics and line or generator outages may cause a progressively and uncontrolled fall of voltages leading to voltage instability or voltage collapse. Voltage stability has become of major concern among the power utilities, because of several events of voltage collapse occurred in the past decade. In this work voltage stability assessment is done.

The advances in high power semiconductor devices led to the development of Flexible AC Transmission System (FACTS). With the development of FACTS devices, power systems have been able to operate much nearer to its stability limits. FACTS devices affect the voltage stability significantly by providing suitable reactive power support. Static VAR Compensator (SVC) and Static Synchronous Compensator (STATCOM) are the shunt connecting devices and most suitable for voltage control. SVC is thyristor based controller, whereas, STATCOM is voltage sourced-converter based controller. In this thesis voltage stability assessment is done for the power systems with SVC as well as for the systems with STATCOM. The steady state models of SVC and STATCOM are presented.

Many performance indices such as, sensitivity factors, singular values and eigenvalues of load flow Jacobian, second order performance index, voltage instability proximity indicator, real power margin and reactive power margin are in use. Voltage stability is a nonlinear phenomenon and strongly related to saddle node bifurcations. Voltage stability margin is defined as the distance with respect to the bifurcation parameter, from the current operating point to bifurcations point i.e. voltage collapse point. In this work this voltage stability margin is referred to as the loadability margin and used as performance index for voltage stability analysis. Conventional power flow fails to give solution at the point of collapse, because of the power flow Jacobian becoming singular at the collapse point. The continuation method systematically increase the loading level or bifurcation parameter, until a bifurcation is detected. It is used to calculate the loadability margin of the power systems with FACTS device for generating a large number of patterns by varying the loads at each bus randomly.

For the large-scale power systems, having many operational strategies the main issue is to assess its behavior under different conditions with sufficient accuracy and less computing time. The traditional analytical techniques have certain limitations in solving some classes of power systems problems. In recent years artificial neural networks have emerged as a powerful tool due to its ability to map complex nonlinear functional relationships with good accuracy and speed. Artificial neural network have proved to be successful in many areas of power systems.

A three-layered feed forward neural network is proposed to calculate the loadability margin of the power system with FACTS devices. The input features consist of real and reactive power injections, total real load, total real generation, total reactive load and total reactive generation and FACTS device parameters. In case of power systems with SVC, the FACTS device parameters are bus voltage, at which SVC is connected and firing angle of SVC; whereas, in case of power systems with STATCOM, these are bus voltage, at which STATCOM is connected, dc voltage and phase shift angle of STATCOM. Considering the real and reactive power injections at all the buses will form a large input vector to neural network. For large power systems therefore, the size of neural network will increase and more computational time will be required to produce the output. To reduce the curse of dimensionality, a technique based on system entropy method is proposed to select only those real and reactive power injections, which have more effect on loadability margin. The proposed neural network is trained by Marquardt-Levenberg (LM) algorithm for non-linear least square. This algorithm is much more efficient than conjugate gradient algorithm and variable learning rate algorithm, for the network with a few hundred weights as in this work. The proposed method is implemented on IEEE-30 bus and IEEE-118 bus system. The proposed method has performed well for both systems.

One area of researches in neural networks has been concentrated towards the development of new neural architectures and learning algorithm. The key idea is to develop neural networks with high accuracy and less computing time. Parallel self-organizing, hierarchical neural networks (PSHNN) are multi-stage networks in which stages operate in parallel rather than in series. Each stage is a particular neural network trained with suitable algorithm. The same inputs are fed to each stage. It is observed that total network, consisting of small stages, converges faster than a single network of the same size for similar error performance.

In this work a method using PSHNN is proposed to estimate the loadability margin of the power system with FACTS devices. Real and reactive power injections are considered to be input features. In case of power systems with SVC, bus voltage, at which SVC is connected and firing angle of SVC are chosen as additional input variables. Whereas in case of power systems with STATCOM, bus voltage, at which STATCOM is connected, along with phase shift angle and phase angle of STATCOM is selected as additional input variables. To improve the performance of network, K-means clustering is employed to form the clusters of patterns having similar loadability margin. To reduce the number of input features in each cluster, system entropy information gain method is used and only those real and reactive power injections, which affect the loadability margin most, are selected. Separate PSHNN is trained for each cluster. Each stage of PSHNN is trained using scaled conjugate gradient algorithm. The performance of Scaled Conjugate Gradient (SCG) algorithm is benchmarked against that of standard Back-Propagation algorithm (BP), the conjugate gradient algorithm with line search (CGL) and the one-step Broyden-Fletcher-Goldfrab-Shanno memory less quassi-Newton algorithm (BFGS). SCG is fully automated, includes no user dependent parameters and avoids a time-consuming line search. The proposed method is implemented on IEEE-30 bus and IEEE-118 bus system. Once trained, the network produces outputs instantaneously for both systems.

There are lots of uncertainties associated with power system variables due to many unexpected events. These uncertainties can be effectively modeled using fuzzy sets. Hybrid systems combining fuzzy logic, neural networks are providing their effectiveness in a wide variety of real world problems. While fuzzy logic performs an inference mechanism under cognitive uncertainty, computational neural networks offer exciting advantages such as learning, adaptation, fault tolerance, parallelism and generalization. To enable a system to deal with cognitive uncertainties in a manner more like humans, one may incorporate the concepts of fuzzy logic into the neural networks. The resulting hybrid systems is called fuzzy neural, neural fuzzy, fuzzy-neuro or neuro-fuzzy network.

In this work, a multi input, single output fuzzy neural network is developed for voltage stability evaluation of the power systems with FACTS devices by calculating the loadability margin. The proposed method consists of two stages combining unsupervised and supervised learning. The real and reactive loads at all the buses, total real and reactive load, total real and reactive power generation are considered as input variables. In case of power systems with SVC, bus voltage at which SVC is connected, along with firing angle of SVC and reactive power injection by SVC is chosen as additional input variables. Whereas, in case of power systems with STATCOM, bus voltage at which STATCOM is connected, along with dc voltage and phase shift angle of STATCOM are selected as additional input variables. In the first stage, Kohonen self-organizing map is developed to cluster the real and reactive loads at all the buses to reduce the input features, thus limiting the size of the network and reducing computational burden. In the second stage, combination of different non-linear membership functions is proposed to transform the input variables into fuzzy domains. Thus, uncertainties of real and reactive loads, real and reactive generations, bus voltages and FACTS devices parameters are taken into account. Then a three-layered feed-forward neural network with fuzzy input variables is developed to evaluate the loadability margin. The neural network is trained by LM algorithm. The proposed methodology is applied to IEEE-30 bus and IEEE-118 bus systems.

Optimization methods and techniques have been used in various areas of the power systems. These methods and techniques are developing very fast and the power systems operators are required to keep themselves informed about these developments. The interior point method is one of these techniques, which has gained much interest over past twenty years. It offers many advantages over conventional techniques and many times faster. The main advantage of these methods lies in their polynomial complexity property. The calculation of loadability margin to voltage collapse point of power systems can be formulated as nonlinear optimization problem and solved by nonlinear programming techniques.

In this work primal dual interior point method for nonlinear programming is proposed to calculate loadability margin of the power systems with FACTS devices. The objective is to maximize loading parameter and the constraints are real and reactive power balance equations, control and power balance equations of FACTS device. Limits on real and reactive power generations and transformer taps are considered. The method is robust and efficient with reduced solution times. Different types of load models such as, constant power, constant current, constant impedance and ZIP model, on the loadability margin are also investigated. The proposed method is applied to IEEE-30 bus, IEEE-57-bus and IEEE-118 bus system.

The power systems often operate under the constraints imposed by real power losses. This reduces the loadability of the system and does not allow the resources to be fully exploited.

In this work a multi-objective problem is formulated with the objective to maximize the loadability and minimize the real power losses. The constraints considered are real and reactive power balance equations, control and power balance equations of FACTS device. Limits on real and reactive power generations and transformer taps are considered. The problem is solved by primal dual nonlinear interior point method. Weighting method is used to convert the problem into a scalar one. The feed forward multi layer neural network is proposed to calculate proper values of weightages to be associated with each objective. The effects of load model are also studied. The proposed method is applied to IEEE-30 bus, IEEE-57-bus and IEEE-118 bus system. The proposed method produces promising results.

In summary, the loadability margin is calculated for the power systems with FACTS devices, using artificial neural networks, parallel neural networks, fuzzy neural network, interior point method and multi-objective approach.