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Power System Security Assessment using Artificial Neural Network

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Abstract* - The management of power systems has become more difficult than earlier because power systems are being operated closer to security limits, environmental and economical constraints restrict the expansion of transmission network, the need for long distance power transfers has increased and fewer operators are engaged in the supervision and operation of power systems. Voltage instability has become a major concern in many power systems and many blackouts have been reported, where the reason has been voltage instability. The objective of the study was to develop a method to be applicable in practice for on-line voltage stability assessment of long-term large-disturbance voltage stability based on black-box model. The basis of the approach is appropriate modelling of power system voltage stability and computation of the most critical voltage stability margins. A large number of power system operation points and the most critical voltage stability margins are computed to create the model. An essential part of model creation is the selection and extraction of model inputs, on which the accuracy of the model is mainly based. This paper evinces new ideas for on-line voltage stability assessment of black-box model. The requirements and the proposed solution of all steps are presented to provide a step by step procedure for the use. This paper describes an application of classification model to voltage security classification problems. The dissertation results in a black box based generalized algorithm to classify power system security state more accurately.

Keywords: Voltage stability, Voltage security, Voltage collapse, Voltage stability margin, Black box modelling, Performance plot, ROC, Confusion Matrix.

I. INTRODUCTION

Population growth across the globe increases the exponential demand of uninterrupted power supply to the consumers resulted drastically change of Power (voltage/current) causing stress on the power system interconnection. The change of Load and its profile resulted variation of voltage, so the voltage is being considered as the critical parameter and its security also should be our prime concern. Voltage security plays vital role on the larger and wider interconnection power system network. Being as such important parameter in past few years it has gained so much importance and become the hot and favorite topic amongst researchers across the globe.

In this section author should give introduction about his/her research related contents and brief details of its integrated parts.

Voltage stability is a problem in power systems which are heavily loaded, faulted or have a shortage of reactive power. The nature of voltage stability can be analysed by examining the production, transmission and consumption of reactive power. The problem of voltage stability concerns the whole power system, although it usually has a large involvement in one critical area of the power system. Power system stability is defined as a characteristic for a power system to remain in a state of equilibrium at normal operating conditions and to restore an acceptable state of equilibrium after a disturbance. A power system becomes unstable when voltages uncontrollably decrease due to outage of equipment (generator, line, transformer, bus bar, etc.), increment of load, decrement of production and/or weakening of voltage control. According to reference [**27**] the definition of voltage instability is “Voltage instability stems from the attempt of load dynamics to restore power consumption beyond the capability of the combined transmission and generation system.” Voltage control and instability are local problems. However, the consequences of voltage instability may have a widespread impact. Voltage collapse is the catastrophic result of a sequence of events leading to a low-voltage profile suddenly in a major part of the power system.

The power system should be operationally secure, i.e. with minimal probability of blackout or equipment damage[1]. An important part of power system security is the system’s ability to withstand the effects of contingencies. A contingency is considered to be an outage of a generator, transformer or line, and their effect is monitored with specified security limits. The objective of power system operation is to keep the power flows and bus voltages within acceptable limits despite changes in load or available resources. From this perspective, security may be defined as the probability of a power system’s operating point remaining in a viable state space[2]. Security assessment is a combination of system monitoring and contingency analysis. It is extremely uneconomical, if not impossible, to build a power system with so much redundancy that failures never cause an interruption of load on a system. Security assessment is analysis performed to determine whether, and to what extent, a power system is reasonably safe from serious interference to its operation [3]. Thus, it involves the estimation of the relative robustness of the system in its present state or in near-term future state.

II. SYSTEM MODEL

The states of power system are classified into five states: normal, alert, emergency, extreme emergency and restorative [4]. The classification of states is used in the analysis and planning of power system. Figure 1 describes these states and the ways in which transition can occur from one state to another.

The operation of a power system is in a normal state most of the time. Voltages and frequency of the system are within the normal range and no equipment is overloaded in this state. The system can also maintain stability during disturbances considered in the power system planning. The security of the power system is described by thermal, voltage and stability limits. The system can also withstand any single contingency without violating any of the limits.

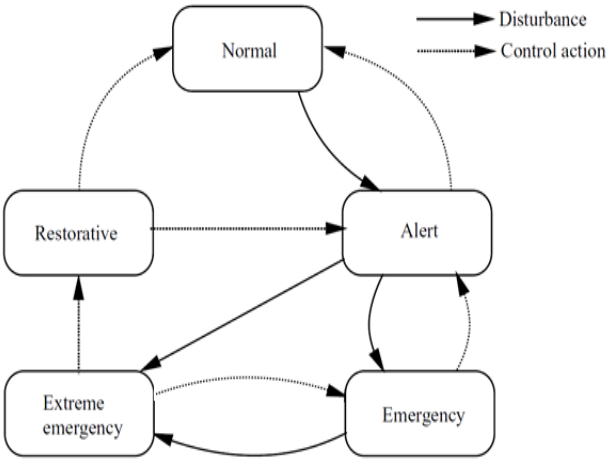

Fig. 1 Power system operating states.

The alert state is similar to the normal state except that the above conditions cannot be met in the case of disturbance. The system transits into the alert state if the security level falls below a certain limit or if the possibility of a disturbance increases e.g. because of weather conditions. All system variables are within the normal range and all constraints are satisfied in the alert operation point. However, the system has been weakened to a level where a contingency may cause a breaking of security limits. This will lead to a transition into an emergency state or in the case of severe disturbance into an extreme emergency state. Control actions, such as generation rescheduling, increased reserve, voltage control, etc., can be used to restore the system back to normal state [5]. If this does not succeed, the system stays in the alert state.

The system transits into the emergency state if a disturbance occurs when the system is in the alert state. Many system variables are out of normal range or equipment loading exceeds short-term ratings in this state. The system is still complete. Emergency control actions more powerful than control actions related to alert state can restore the system to alert state. The emergency control actions include fault clearing, excitation control, fast valving, generation tripping, generation run-back, HVDC modulation, load curtailment, blocking of on-load tap changer of distribution system transformers and rescheduling of line flows at critical lines [6].

The extreme emergency state is a result of the occurrence of an extreme disturbance or action of incorrect or ineffective emergency control actions. The system is in a state where cascading outages and shutdown of a major part of power system might happen. The system is in an unstable or close to an unstable state. The control actions needed in this state must be really powerful. Usually load shedding of most unimportant loads and separation of system into small independent parts are required in order to transit the system into a restorative state [7]. This is only a possibility, because many production units are shut down due to too high or low frequency or any other reason. The aim of the actions is to save as much of the system as possible from a widespread blackout. If these actions do not succeed, the result is total blackout of the system.

The restorative state is a transition state between the extreme emergency and normal or alert states. It is important to restore the power system as fast and securely as possible in order to limit the social and economic consequences for the population and economy. The restoration time depends on the size of interrupted area, the type of production in the system, the amount of black start capability in the system and the possibility to receive assistance from interconnecting systems [8]. The restoration process includes reconnection of all generators, transmission lines, loads, etc. Two major strategies for power system restoration following a blackout are the build-up and the build-down strategy [9]. The build-up strategy is the most commonly used strategy. The system is divided into subsystems where each subsystem should have the capability to black start and control voltage and frequency. After the synchronization of production unit’s loads are gradually connected. The connections to other subsystems are then synchronized.

III. SECURITY ASSESSMENT

The following description is based on off-line security assessment procedure found through security assessment software. The same procedure can be used in the on-line security assessment, if the execution time is fast enough. The fundamental difference between off-line and on-line security assessment is the difference in input data. On-line security assessment analyses the current operation point given through the SCADA and the power management system, while off-line security assessment ensures the security of a future operation point. It is based on near future planning data, which must be predicted. The future operation points consider network topology, generation dispatch, unit commitment, load level, and power transactions. The uncertainty of these factors causes the need for numerous security assessment studies. As these possible variations increase, the number of operation points which must be studied becomes unmanageable, even in short-term planning cases. In on-line security assessment the variations of network topology, unit commitment and load level need not to be considered. The number of possible variations to be studied becomes manageable and the stability limits obtained on-line are expected to be more accurate. However, the execution time of security assessment is much less in on-line than in off-line mode.

Figure 2 is a schematic diagram of security assessment and determination of security limits. The main features of the security assessment are contingency selection, security analysis using either load-flow or time domain simulation, and determination of security limit. Contingency selection helps to identify the critical contingencies for the detailed security analysis. The analysis of all contingencies is too time-consuming and is not necessary in practice. Security analysis uses a short contingency list to check the security of the power system. The short contingency list includes those contingencies which are most probably critical. The traditional approach to planning for voltage security relied on ensuring that pre-contingency and post-contingency voltage levels were acceptable. This criterion is based on equipment tolerances and it ensures safe voltages. However, a system may have healthy pre-contingency and post-contingency voltage levels, but be dangerously close to voltage instability. That is why the security analysis should also provide an index to assure that sufficient voltage stability margin exists.

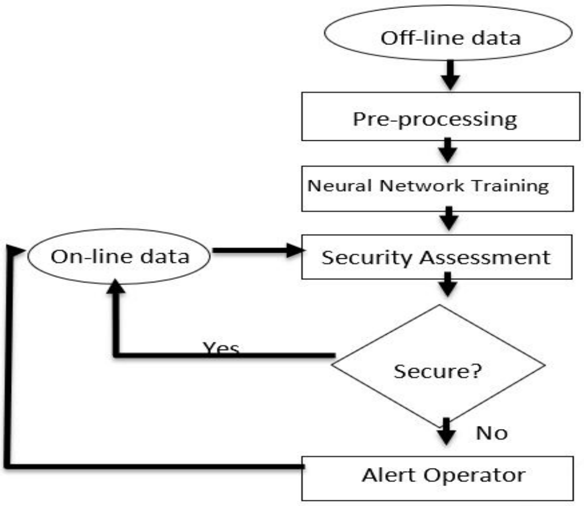

Fig. 2 Flow chart of Security assessment and determination of security limits

The security assessment should be done on-line to get a real picture of the power system state. In practice, the security assessment is done every 5-10 minutes, because changes of operation point are normally small and slow, and long-term security analysis of practical size power system takes several minutes, e.g. 12 minutes according to reference [**6**]. The estimate is based on a computation time (PC 486, 66 MHz) of long-term security limits (about 10 load-flows per PV-curve) for 14 contingencies of a 4000-bus test system. Reference [Hir99] mentions that the dynamic security analysis of 30-40 contingency cases can be done in 20 minutes using parallel processing to determine the transfer limits of a critical interface.

IV. BLACK BOX MODELLING

The models and methods are described here to provide the basic knowledge about black-box modelling in order to understand their application. The models described are regression model, multilayer perceptron and radial base function neural networks. Neural networks may be understood as non-linear and powerful counterpart for traditional statistical methods like classification models from statistics and computer science point of view. The parameter estimation of these models is also described here. The generalization capability of the model is the most important aspect of modelling. Black-box models are applied when the functioning of a system is unknown or very complex (there is not enough knowledge to create a physical model, the system is very non-linear and dependent on operation point or the analysis of the system is time-consuming), but there is plenty of data available. The simplest form of black-box models is probably tabulation of measurement data. The data may also be presented with selected prototypes, which are for example the mean values of certain parts of the data. This form of models may be created by clustering methods. The presentation of the data with tabulation and prototype models is very sparse, because the data is presented only in local points of data set. Local function approximation is a concept where each prototype represents a continuous function in own subset. The radial base function neural network is the most well-known local neural network algorithm, other traditional statistical methods are splines. These models are capable of approximating the functioning of the system at the same level as physical models when sufficiently comprehensive data is available. The multilayer perceptron neural network is capable of global function approximation, i.e. it represents a function in a whole data set. The statistical regression model is also capable of accurate function approximation, but the applicability is usually limited to small scale (the number of parameters is small) and non-complex problems.

V. EXPERIMENTAL RESULTS

A. Load Variation

Researcher has done performance analysis of implemented work on MATLAB platform. The analysis of secure and insecure cases out of total cases is done. In figure 3, the bar graph is shown which showing the total cases, secure cases and unsecure cases of corresponding bus system, and in figures 4 to figure 5 showing the power variation of corresponding bus system. figure 3 Bus System vs. Number of Instances.

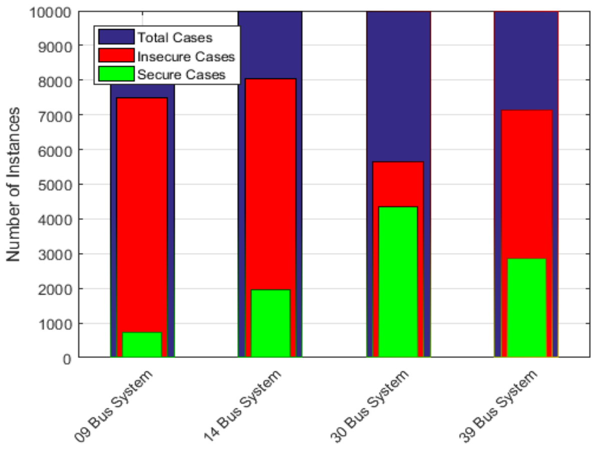

Fig. 3 Bus system Vs. Number of instances

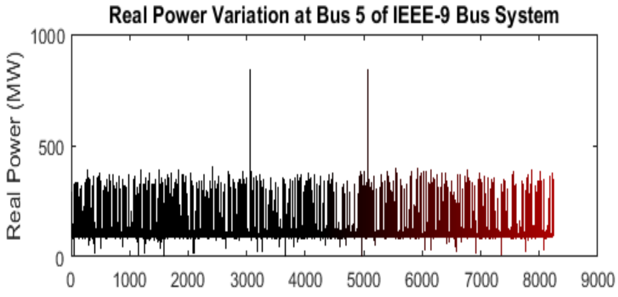

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Fig. 4 Real Power Variation at Bus 5 of IEEE 9 Bus

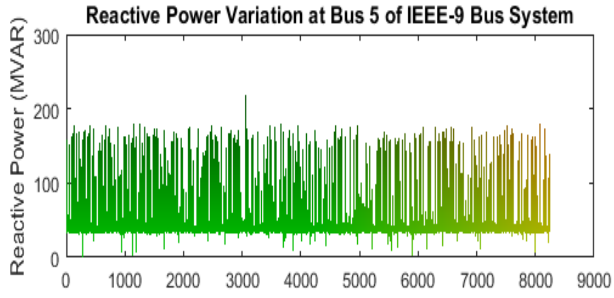

Fig. 5 Reactive Power Variation at Bus 5 of IEEE 9 Bus

B. ANN Model Analysis for IEEE-9 Bus System

The Artificial Neural Networks (ANNs) has been designed. As earlier has been discussed, in designing of ANNs, training, validation and testing of is necessary steps to get more accurate classified result. In figure 6, Performance plot of the network trained, validated and tested for IEEE-9 Bus system is shown. As in the plot, Cross-Entropy is plotted on y-axis and number of epochs is plotted on x-axis. The Cross-Entropy decreasing continuously as the number of epochs is increasing but after 85 epochs the separation between validation curve and training curve is increasing. So, researcher has stop to train the network at 85 numbers of epochs. The best validation performance achieved by network is 0.016961 at 84 epochs. In the figure 7, Confusion Matrix for training of IEEE-9 Bus system are shown. In which diagonal elements are indicating correctly classified number of samples and other element indicating number of misclassified samples. Accuracy of classification is defined from the confusion matrix.

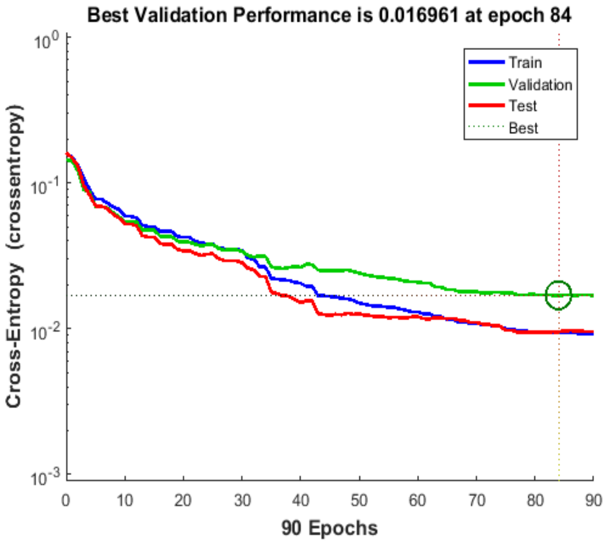

Fig. 6 Performance Plot of the Network for IEEE 9 Bus System

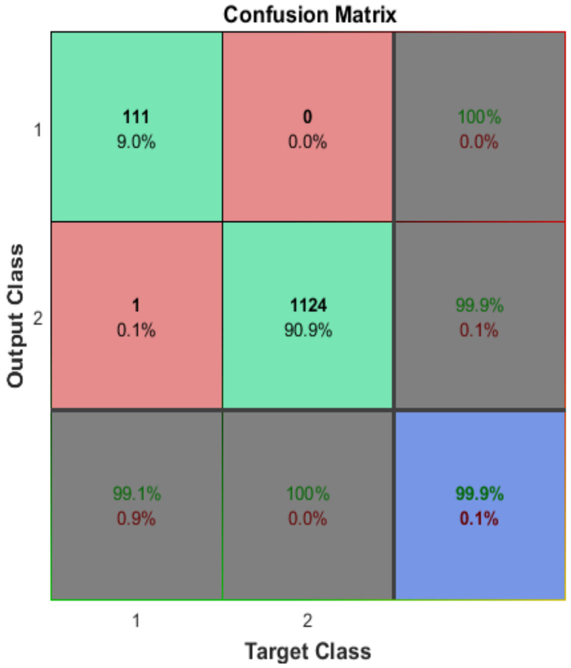

Fig. 7 Confusion Matrix for testing set of IEEE 9 Bus System

VI CONCLUSION

The dissertation proposed a model-based approach for the on-line assessment of long-term voltage stability. It also includes descriptions of the voltage stability problem, on-line voltage stability assessment, computation methods of voltage collapse point, contingency ranking methods for non-linear problems and black-box modelling. The proposed approach is intended for the determination of the power system state and the estimation of the available transfer capacity, and may be implemented as a decision support tool for the power management system.

The approach was successfully applied to the approximation of the most critical post-disturbance voltage stability margin of the IEEE 9, 14, 30 and 39 bus systems equivalent system of the Finnish power system. The results prove the ability of the proposed approach to approximate the voltage stability margin. The test results also show the comparison of different feature selection and extraction methods, parameter estimation algorithms and model types. The best results were achieved with the multilayer perceptron neural network and principal component analysis. The advantage of linear polynomial models compared to neural networks is the fast parameter estimation and capability to easily estimate the uncertainty of model parameters with confidence limits.

VII FUTURE SCOPE

Based on the Implemented Research work and near future challenges following aspects need further investigation.

- Work can be carried out for voltage security assessment by considering multiple generator and line outages.
- Voltage security assessment can be carried out by considering distributed generation along with conventional power generation.
- Investigation can be carried out to find out more efficient technique to consider dynamic and transient security assessment simultaneously.
- Find out suitable approaches and control strategies to tackle increasing problem of cyber-attack on power system.

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