

Voltage Stability in Power Systems using Artificial Intelligent Approaches

Muhsin Tunay GENÇOĞLU, Burak YILDIRIM

Abstract— The events such as the increase of load demands constantly in power systems, the continuous growth of electricity networks, the use of new technologies and the controls have led to the emergence of system stability problems in different structures. For the design and operation of the power system in the optimum level, instabilities in different ways and their relations with each other should be revealed clearly. To prevent great economic losses in the system as a result of the possible instabilities, it is necessary to predict stability criteria and do the necessary regulatory works. In this study, critical values for the system voltage stability have been obtained with the Power System Analysis Toolbox (PSAT) program. By using obtained values, artificial neural network (ANN) and least squares support vector mechanism (LSSVM) algorithms have been determined with the voltage stability critical values. The achievements of ANN and LSSVM algorithms, trained with the help of power system voltage stability critical values obtained under different conditions, on the voltage stability analysis have been shown. Therefore, voltage stability analyzes have been carried out by establishing 13 busbar power system in Elazığ in the North-eastern Anatolia region. According to obtained the results, a very successful fixation of voltage stability has been carried out.

Keywords— voltage stability, artificial neural network, least squares support vector mechanism, power system analysis toolbox.

I. Introduction

In the sense of a system, which is in the given primary working condition, power system stability is being able to ensure balance in case of any physical problem encountered. Stability in power systems can also be defined as working of the power system in stable working conditions and ensuring an acceptable balanced state after affecting from a possible breaking factor [1].

Problem of voltage stability is one of the most important stability problems of the power system. The problem of voltage stability can be defined as the ability of keeping voltage values of load bus bars in a power system within specific operating limits in every condition that may occur. It can be seen that there is an increasing interest in the subject of voltage stability. This increase can be associated with the adverse events, which happened recently in different regions of the world [2-3].

Problem of voltage stability occurs when voltage level of load bus bars in power systems decreases and enough reactive power cannot be produced and given to the power system. If the voltage value decreases under the critical values, which are important for the voltage stability, a voltage collapse will appear in some parts of the system or even within the whole system.

As developed by inspiring from the human brain, ANN is a parallel and distributed data processing structure that employs some operation units, which have their own memories and are connected to each other with links called as weights. In other words, ANN is a program, which simulates neural networks in our brains. ANN is also examined under some titles like connectionism, parallel distributed operation, neural-operation, natural intelligence systems and machine learning algorithms. Today, ANN is the new generation of information processing systems. Generally, ANN is very successful at operations like system model choice and classification, function prediction, finding the most appropriate value and data classification [4].

Support Vector Machines (SVM) can be employed in classification and regression problems. Essential idea in the SVM regression method is to find the linear discriminant function, which is suitable to the theory of statistical learning and reflects the character of training data to as close to reality as possible. As similar to the classification, regression uses kernel functions in case of non-linear situations, too. SVM is an effective solution method, which can be used for frequency prediction and non-linear classification. SVM models can also be defined in the content of structural risk minimizations and theories of statistical learning [3, 5].

PSAT program is a MATLAB toolbox, which can be used for controlling power systems and performing static and dynamic analyzes. PSAT program comes with the sections of power flow, optimal power flow, ongoing power flow, small signal stability analysis, and time area simulation [6].

In this study, critical values of voltage stability have been determined by using ANN and LSSVM algorithm. By using the PSAT program, a model of 13 bus bar power system, which includes specific load bus bars from North-Eastern Anatolia Region city in Turkey-Elazığ has been formed. With this model, related voltage stability critical values for different load values have been obtained. Thanks to these values, training processes of ANN and the LSSVM algorithm have been performed. In this way, voltage stability critical values, which are related to different change values in bus bar loads of the power system, have been determined by using ANN and LSSVM based application.

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II. Voltage Stability

Voltage stability is the ability of voltage values in all bus bars of a system being in acceptable values in the normal working state or even after affecting from a breaking factor. In any breakdown like increase in load demand or change in system conditions leading uncontrolled or continuous decrease in voltage, the system has the state of unstable voltage. The main factor causing to the instability is the system, which is not enough to meet with the reactive power demand. Background of the problem is mostly based on decrease in the voltage, which occurs in active and reactive power flow over the inductive reactants related to transmission line. The criterion for the voltage stability is the increase in voltage amplitude of the bus bar in the time of increase in reactive power of the same bus bar; in the working condition given for each bus bar in the system.

As the voltage, the system is unstable if the voltage amplitude of the bus bar decreases in the time of increase in reactive power of the same bus bar; at least for one bus bar in the system. In other words; as the voltage, the system is stable if $V - Q$ sensitivity is positive for each bus bar and the voltage is unstable if the $V - Q$ sensitivity is negative for at least for one bus bar.

Continuous decrease in bus bar voltage is related to taking rotor angles to the nominal working state. For example; while rotor angle between two machine group closes to 180 degree or exceeds it, gradual synchronization lose in the machines will cause too low voltage values in the middle of networks. On the other hand, continuous voltage decrease state, which occurs in the way when the rotor angle stability is not subject, is related to voltage instability. Actually, voltage instability is a regional event. Furthermore, its results may have wide effects. Voltage collapse is more complex than simple voltage instability and mostly it is related to events, which lead to voltage instability causing low voltage in important part of the system [1, 7].

Stability values should be calculated in order to design power systems by preventing from stability problems and making the system working ideally by determining stable working points of the system. Several methods are used in order to determine values of the voltage stability, which is one of the related stability factors.

The Jacobian matrix of the power flow equations becomes singular over the voltage stability limit. Continuous power flow method can overcome this problem. The continuous power flow finds the load solutions, which follow each other according to a load scenario.

Continuous power flow includes prediction and correction steps. As an essential solution, a tangent prediction is used in order to predict next solution for one sample of the load increase. Then the correction step determines the certain solution by using Newton-Raphson technique, which works via a conventional power flow. After that, a new prediction is done a new increase defined in the load according to a new tangent vector. Then the correction step is applied. The related process continues until the critical point is reached. Critical point is the one, on

which the tangent vector is zero [8-10]. Steps regarding to prediction and correction approaches are shown in Figure 1.

More in load flow, first power flow equations are formulated again by adding a load parameter to these equations [11]. As shown below, the added powers can be written for i^{th} bus bar of an n -bus bar system [12]:

$$\begin{aligned} P_i &= \sum_{k=1}^n |V_i||V_k|(G_{ik} \cos \theta_{ik} + B_{ik} \sin \theta_{ik}) \\ Q_i &= \sum_{k=1}^n |V_i||V_k|(G_{ik} \sin \theta_{ik} - B_{ik} \cos \theta_{ik}) \\ P_i &= P_{Gi} - P_{Di}, Q_i = Q_{Gi} - Q_{Di} \end{aligned} \quad (1)$$

Here, G and D indices are for load demand and the generations for the related bus bar, respectively. In order to simulate a load change, a load parameter λ is added to the demand powers P_{Di} and Q_{Di} .

$$\begin{aligned} P_{Di} &= P_{Di0} + \lambda(P_{\Delta base}) \\ Q_{Di} &= Q_{Di0} + \lambda(Q_{\Delta base}) \end{aligned} \quad (2)$$

P_{Di0} and Q_{Di0} are because of load demands at i^{th} bus bar. However, quantity of λ scale chosen powers were given as suitable to $P_{\Delta base}$ and $Q_{\Delta base}$. Equations can be defined as new array after adding new demand powers in (2) to the (1):

$$F(\theta, V, \lambda) = 0 \quad (3)$$

Here, θ is vector of bus bar voltage angles and V is the size of bus bar voltage. For $\lambda = 0$, an essential solution was found with power flow way. After that, sustained and parameterization processes are applied [8].

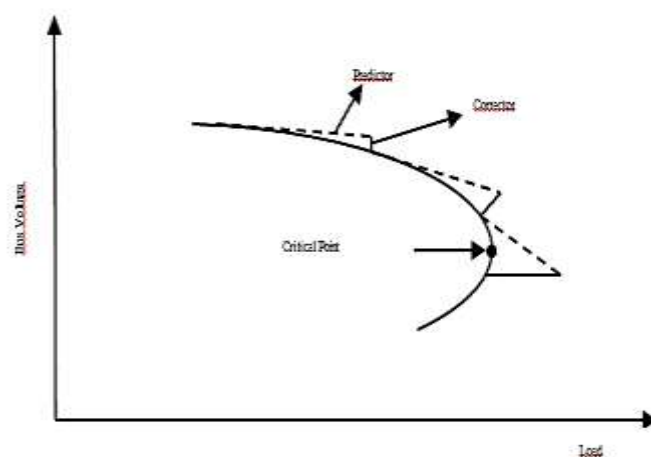


Figure 1. Illustration of prediction-correction steps

III. Artificial Intelligent Approaches

A. ANN

ANN has been being applied in many fields including information classification and interpretation. Essential application approaches of the ANN are classification, prediction, and modeling.

Classification: Customer/Market profiles, medical diagnosis, signature examinations, evaluations on risk / borrowing, voice recognizing, shape recognizing, spectrum defining, goods value, classification of cell types, microbes, models, examples.

Prediction: Next sales, production need, market performance, economical evidences, energy need, medical results, chemical reaction products, weather forecasts, horse racings, environmental risk, jury panels.

Modeling: Process control, system control, chemical structures, dynamic systems, sign comparing, plastic molding, source control, robot control and many other applications [4].

B. LSSVM

SVM is a powerful method for solving problems in linear and nonlinear classification, function estimation and density estimation. LSSVM are least squares versions of SVM. LSSVMs are a class of kernel-based learning methods. While SVM represents the quadratic programming problems, LSSVM classifier are obtained by solving a set of linear equations. Quadratic programming methods used to solve the optimization process in the standard SVM classifiers is not used in this technique. Instead, it uses a set of linear equations. LSSVM classifiers were proposed by Suykens and Vandewalle [13-14].

IV. Simulation

Single line schema of the 13 bus bar power system is shown in Figure 2. Voltage stability critical values related to the system run on PSAT program and change of active and reactive power values of bus bars after multiplying with 0.5, 1, and 1.5 are shown in the related figures; for different bus bars.

Change of voltage stability critical values of Elazig bus bar is shown in Figure 3. At this point, V_{crit} value changes (with changing load bus bars by multiplying 0.5, 1, and 1.5) of Elazig bus bar at different load states is also given in Figure 3. When we examine values in Figure 3, it can be expressed that the biggest V_{crit} value is 0.9695 and it has been obtained with the iteration at the 165th step. The smallest V_{crit} value in Figure 3 is 0.6250 and this value has been obtained with the iteration at the 1411th step. Multiplier values of bus bars at the iterations in which the biggest and the smallest V_{crit} values have obtained are as follows. In the biggest value is 0.5 and in the smallest value is 1.5.

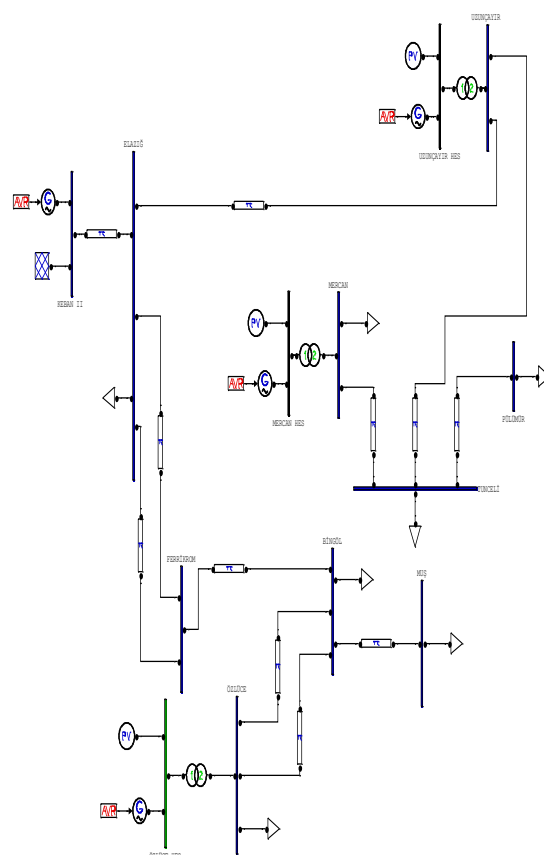


Figure 2. 13 bus bar power system

Results of ANN and the LSSVM algorithm related to 13 bus bar real power system is given as graphically. In the training and test processes of ANN and the LSSVM algorithm, data regarding to the system, whose single line schema is shown in Figure 3 has been used. By using the information of 7 load bus bar in the 13 bus bar system, training and test processes of the ANN and the LSSVM algorithm have been performed. In the training and test processes, multiplier values showing active and reactive power change quantity have been used as the input. At the output, V_{crit} values obtained from the PSAT program take place. In this sense, the input is 7 dimension vector matrix and the output is 7 dimension vector matrix forming critical values regarding to 7 bus bars. In order to evaluate success of ANN and the LSSVM algorithm in the 13 bus bar real system, V_{crit} values at different load states have been obtained at the top section. From these data, a 500 of them, whose active and reactive power change quantities have been formed via 0.5, 1, and 1.5 multipliers and which have been chosen randomly from a total of 1493 data regarding to each bus bar, has been used along the training process. Other remaining data has been used as the test data.

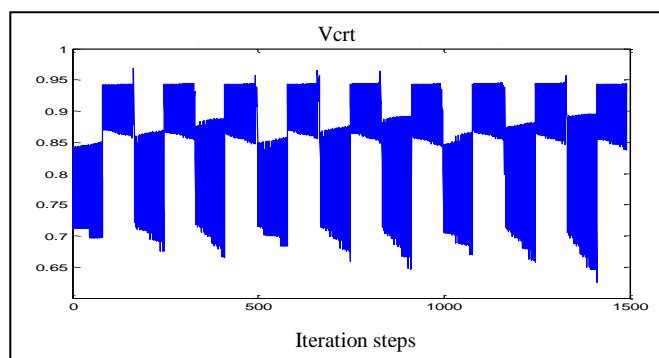
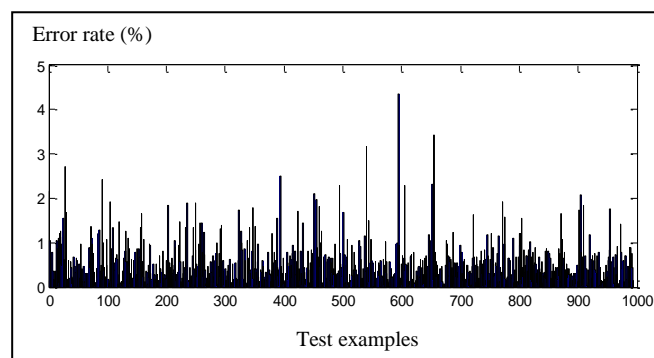
Figure 3. Change of V_{crit} values related to Elazig bus bar

Figure 5. LSSVM predictions related to the Elazig bus bar

In the training and test processes of these data, parameters shown in Table 1 have been used. On the other hand, parameters presented in Table 2 have been used for training and test processes of the LSSVM algorithm. Error rates of prediction processes obtained with multipliers 0.5, 1, and 1.5 and next are shown as in % within the related figures.

Prediction results obtained in Figure 4-5 are for 0.5, 1 and 1.5 values of bus bar change. Error quantities regarding to random 993 predictions done by ANN algorithm for the Elazig bus bar is shown in Figure 4. Average error of predictions done by the ANN is 0.8759. On the other hand, error quantities regarding to random 993 predictions done by LSSVM algorithm for the Elazig bus bar is shown in Figure 5. At this point, average error of predictions done by the LSSVM is 0.4708.

TABLE I. ANN ALGORITHM PARAMETERS

Number of Inter-Layer	55
Momentum Rate	0.25
Learning Rate	0.95
Learning Algorithms	Levenberg-Marquardt
Activation Function	Tansig.

TABLE II. LSSVM ALGORITHM PARAMETERS

Kernel Type	RBF Kernel
Rearrangement Parameter ($\hat{\alpha}$)	50
Kernel Parameter (Sig6)	1.1

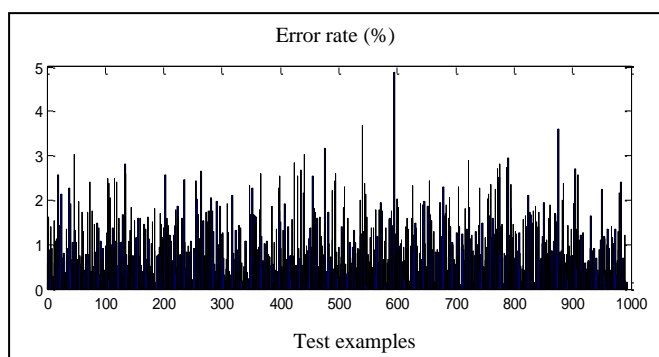


Figure 4. ANN predictions related to the Elazig bus bar

v. Conclusions

In this study, voltage stability critical values have been determined for different load conditions, by using a real 13 bus bar system, which has been formed as including some load centers located in Elazig city of North-Eastern Anatolia Region in Turkey. While creating different load conditions, active and reactive power rates of the load bus bars have been increased by 50% and decreased by 50%. 1493 different voltage stability values for 0.5, 1, and 1.5 multipliers have been obtained for 7 separate bus bars. Having different training and test data formed with these values, success states of ANN and the LSSVM algorithm have been examined in the sense of the related systems. In the voltage stability detection process, LSSVM algorithm has provided better performance than ANN. As a result of this study, it has been determined that voltage stability critical values are determined accurately by using ANN and the LSSVM algorithm in the voltage stability analysis of an electric power system. ANN and LSSVM provide very successful results in determining voltage stability critical values, which is an important parameter in energy systems and also an essential subject in analysis of those systems. According to the obtained results, we can express that usage of ANN and LSSVM makes a significant contribution to calculation of voltage stability critical values, whose rapidly prediction is an important factor.

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