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Different Voltage Security Assessment Methodology in a Restructured Electricity Market: A Review

Sonali R. Nandanwar
Electrical Engineering dept.
Priyadarshini College of Engineering
Nagpur, India.
sonalinandanwar@gmail.com

S. B. Warkad
E.E.E. dept.
C.D.G.I., Indore
M.P., India
sbwarkad@yahoo.co.in

***Abstract*—This paper presents the different methodologies of Voltage Security Assessment (VSA) in a restructured electricity market. In this paper classification provided on the basis of various researchers studied for review. It provides an up-to-date overview which is fully focused on i) Contingency analysis ii) Decision tree (DT) iii) Phase Measurement Unit (PMU) iv) Case Based Reasoning (CBR) v) Neural Network based methods vi) Simulation Methods vii) Restructured Electricity Market. Assessment done by various authors has real and reactive load, Severity of contingency, statistics, Machine Learning, pattern recognition, data mining considered. Finally number of references is given that describes a detailed analysis.**

Keywords— Voltage security assessment, decision tree, phase measurement unit, case-based resoning, restuctured electricity market, Continuous Power Flow (CPF)

I. INTRODUCTION

The complexity of the modern power system is continuously growing due to the ever-increasing interconnections and load demand. Because of economical and environmental constraints, utilities are facing difficulty in constructing new transmission system and generation facilities. Due to these reasons there is a trend in modern power systems towards greater utilization of generation & transmission capacity, which means that the systems are required to operate much closer to their security limits. Large amount of real and reactive powers are transmitted over a fairly long EHV lines, while ample supply of reactive power is not available locally. In such situation it is very difficult to maintain voltage profiles at the load buses within acceptable limits, and utilities often face the problem of voltage instabilities. Several events of voltage collapse have been occurred in the past decade, resulting in widespread blackouts with potentially severe social and economic consequences. Hence the study of voltage security has become and an important area of research.

The security function in power system operation can be divided into three components, namely monitoring, assessment and control. Security monitoring starts with the measurements of real time data and state estimation to provide up to date information about current state of the system. Security assessment identities whether the system operating point is secure or insecure. If the system is found to be insecure, analysis proceeds to determine the appropriate corrective strategy. If the system is secure, then security assessment is performed.

Due to disturbances on power system or interruptions may cause the voltage collapses, it affects the economic damage not only can they create considerable loss of production or data, there is also loss of market, the loss of client trust, comfort etc, that incite energy consumers to implement certain form of protection for their systems [2][3]. To mitigate the voltage collapse benders decomposition method [1], P V method [3], PQV method by using artificial intelligence (AI) techniques [4] and from finding interruption cost [2].

Hence security assessment is very necessary in power system study. When disturbance occurs on bus bars of the power system, voltage instability occurs on the system. There are mainly three types of voltage stability, first is Transient stability, Dynamic stability & Steady state stability. Transient stability control is more difficult in current deregulated environment than before [5,6]. During finding the voltage stability changing generation / load patterns cause congestion by using Rotor angle method, it is assessed accurately [5]. In steady state security assessment Mote Carlo method is used, by using probabilistic method [7]. In which contingency analysis done by system security indices [7]

Voltage security assessment (VSA) is done by voltage security operation limits determined by the most critical contingency among the pre-contingency & post-contingency analysis. This done by P-V & Q-V curve method [8, 10, 18, 19]. Contingencies screening, ranking &filtering done by voltage security assessment tool (VSA) which slows dynamics of the system by using Quasi-steady-state system (QSS) [13, 15, 16]. Again VSA find out by look -ahead method [14, 21, 34] by saddle node bifurcation & switching limit loadability (SLL) from which Electrical distribution is measured from operating point to loadability surface [14, 9, 17,20] .

This paper is organized as follows :I) Contingency analysis II) PMU III) Decision Tree (DT) IV) C.B.R. V) Neural Network methods VI) Simulation methods VII) Restructured electricity market as shown in Fig1.

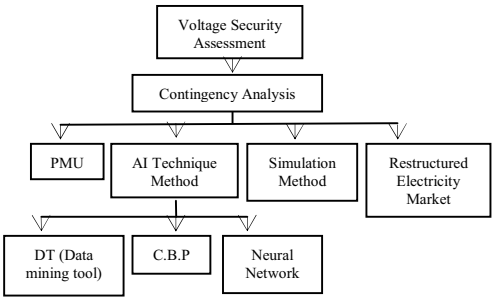

Fig 1. Classification of VSA methodologies

II. CONTINGENCY ANALYSIS

In a large size power system the possible number of contingencies including multiple ones will be an astronomical number. Hence in keeping in view the real time requirement of the security function the aim of contingency definition is to reduce this list to a shorter one containing only credible contingencies [21, 22]. The probability of occurrence of credible contingencies is very high. Even the number of credible contingencies is so large that they cannot be evaluated in time frame of interest [24,25]. Hence the credible contingencies are first ranked in order of their severity and a few, most severe contingencies, are short- listed for evaluation of their effects in a time frame of interest so that necessary preventive control action can be undertaken in Fig. 2 shows the overviews of voltage security function [22, 28]

The traditional methods of contingency selection based on approximate or full Ac load flow are either inaccurate or time consuming. To overcome these difficulties, there is a pressing need to develop fast, accurate and transparent security reassessment tools [29,30].

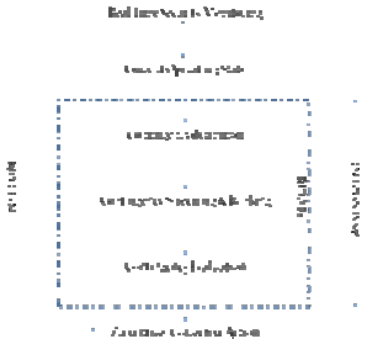
Fig.2. Voltage security assessment flow chart

In contingency evaluation, screening and ranking of the load buses or line outages are carried out by voltage collapse proximity indicator (VCPI) [22], regression tree(RT)[29], continuation power flow(CPF), generalized curve fitting (GCF)[28], adaptive bounding [30]. The damped Newton method is used for finding voltage of reference bus voltage at post-contingency nose point. This is done by using PV curve method [27]. A parallel radial basis function neural network which is multistage network in which stages operate in parallel rather than in series during testing [24,36,37,38,39], it is an Artificial Neural Network(ANN) based method [23, 26, 25, 40, 41]. In contingency analysis performance index (PI) decide the rank of particular contingency. The PI given in equation (1) tries to include the effect of both under/ over load lines and under/ over voltage buses to decide the ranking of contingencies. [32, 35] .

$$PI = \sum_{\substack{l \\ \text{All Branches}}} \left[\frac{P_{flow\,l}}{P_{l\,max}} \right]^{2m} + \sum_{\substack{i \\ \text{All Branches}}} \left[\frac{\Delta E_i}{\Delta E^{max}} \right]^{2m} \quad (1)$$

$P_{flow\,l}$ - Real power flow in line l

$P_{l\,max}$ - Maximum loading capacity of line

ΔE_i - Diff. between voltage magnitude after nPQ solution and base case voltage magnitude

ΔE^{max} - Value set by utility experts indicating how much maximum voltage deviation is allowed at any bus

m, n - are integers generally taken between 3-5

The ranking list based on PI is sorted out in such way that contingency with highest value of PI is placed at top and so on. To this end author propose the following three-stage approach

A. Screening stage: perform the task of contingency screening to screen out contingency which are definitely voltage stable from asset of credible contingencies

B. Ranking stage: perform the task of contingency ranking in terms of load margin for each contingency remaining in stage 1.

C. Detail analysis stage: perform detailed analysis via computation of P-V ,Q-Vand P-Q-V curves for the top ranked contingencies[20,21,34]

The VSA in the power system operating planning applies the N-1 criterion in order to evaluate the voltage security impact provoked by contingencies [48]. In voltage security by loadability computation by means of the power flow computation (CPF) [47].

III. PMU BASED METHOD

Phasor measurement units (PMU) are used in power system that provides synchronized measurements. From GPS, bus voltage and line currents synchronicity is achieved by time-sampling of voltage and current waveforms using timing signals. PMU measured is metered to the control centre via microwave channels or any other land base communication links [63,67].

PMU Placement Strategy: The PMU need high-speed communication facilities for sending real time data to a central location. It is very important to realize that excessive input data to the DT could lead to inaccurate decision by the DT. As a result, intensive studies were performed for all the combinations among these substations that can be used for the best decision for Q-tree (reactive flow) and AD-tree (bus angular differences). In addition, some substations without communication have also been found to be useful PMU locations. If communication facilities could be added to these locations, the accuracy of the final decision will be improved [66].

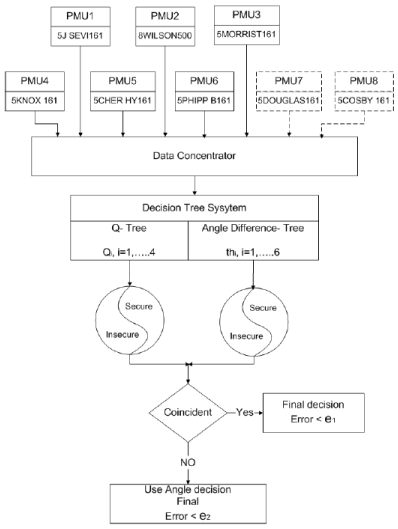

Fig 3. Structure of the voltage security monitoring system

AD- Tree vs. Q tree: The following serves to clarify the reasons selecting the AD- tree if the results differ between Q-tree and AD-tree. The AD-tree and Q-tree produces identical results if and only if the reactive powers produced by the generators don't hit their limits. So using the Q-tree will enhance the voltage security classification accuracy. In addition, for small number of PMU placement the number of angular displacement attributes is quite small (AD-tree is not so accurate) however, the number of Q measured (number of incident branches to PMU location) is quite large. Q-tree is more accurate than AD-tree for small number of PMU located in the system as shown in Fig3. [66].

The DT's are first trained offline and periodically updated for further improvement. In voltage security assessment, severe contingencies can be obtained by comparing the PMU measurement with the attributes in the DT's in real time.

IV. DECISION TREE

It is well-known method in data mining and classification problems with high data dimensions [52,61].DT use security assessment step once the DT have been validated, they may be used to formulate security criteria and derive appropriate operating strategies [54]. A DT is a tree structured predictive model for a given 'objective' characterized by a vector of attributes or predictors. Based on the nature of the objective. DTs can be categorized as classification trees (CT) and regression trees(RT) respectively. In this effort, all CTs and RTs are trained and tested using a commercial package, called classification and regression tree (CART)[55,58,60] .In CART DT is a binary tree constructed by splitting a node into two child nodes repeatedly, beginning with the root node that contains the whole learning samples and progressing down to the terminal once. At each step, a set is divided into two 'purer' subsets. Fig.4. illustrates the basic function of DT that expressing input information through binary rules. The general DT training algorithm learns from the examples and enables one subsequently to infer knowledge about new unseen cases [57, 62, 64].

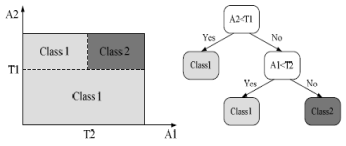

Fig. 4. Input space and corresponding decision tree

The performances of these smaller DTs on the test set are scored in terms of the misclassification cost for CTs and mean-square error for RTs. The Optimal tree is therefore defined as the tree model with the lowest prediction error on the test set [55]. In on-line VSA consist of five major steps

A. Prediction of load and generation variation Scenarios.
B. Database Generation[53]
C. Prediction Model Training
D. Evaluation of Predicted scenarios and
E. Online application

In this method, three important assumptions are made: 1. In normal and contingency condition, the network is fully observable, 2. In the occurrence of contingencies, power flow equations never diverge, and 3. every transition from pre contingency to post contingency occurs without suffering any transient instability phenomenon [52].

The voltage collapse problems caused by severe perturbances in the system. To overcome from this problem a three-step DT based scheme for on-line voltage security assessment using pharos measurements [56, 57, 58, 63] can be used. The main procedures include 1) From past database, predicted operating conditions (OCs) and training offline DTs databases can be conducted detailed post contingency analysis. 2) After checking the system is secure or insecure DTs are updated periodically by including anticipated OCs for the next hour to reduce the likelihood of misclassification. and 3) By collecting the PMU measurements selected as critical attributes in the DTs by comparing the threshold values in the DTs. So the sever disturbances in the system can be obtained. The proposed scheme take full advantage of all available PMU measurement across a system to asses post contingency voltage security [56, 65].

To investigate the state of DT methodologies, a review of 31 papers published during 2000 to 2013 has been made on the 1) PI 2) Data base generation 3) Model Training 4) Online Application. During model training following Table I is given for secure and insecure cases on the basis of database which is given by different authors.

TABLE I

No of paper published	No of DT's	Learning set accuracy in %			Testing set accuracy in %		
17	DT_1.....DTn	Insecure	Secure	Overall	Insecure	Secure	Overall

V. C.B.R. METHOD.

The CBR is comes under Artificial Intelligent (AI) methodology it extract the information of voltage security by varying the real and reactive loads at PQ buses which are screened offline. In real time frame data base may be created by previous record. The severity of contingency for each case with respect to different contingencies is assessed by number

of secure and insecure operating states, which are predicted by C.B.R Security classes, are defined by threshold value of maximum loadability margin, calculated using CPF analysis [68].

Components of CBR: Fig.5.shows the cycle of CBR which has been used for voltage security assessment. There may be variation in this cycle depending on the application and features used. Main components of the CBR are given below.

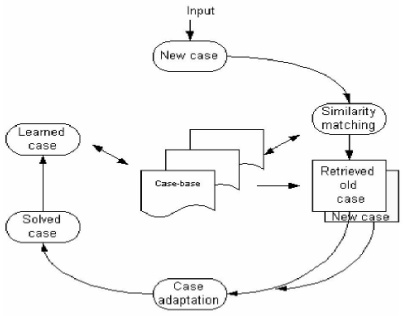

Fig. 5. Cycle of case based reasoning.

a) *Case representation*: A good representation of cases will for instance allow for identification of important properties of a problem and use these properties for the justification of decisions. Most of the CBR systems represent the cases as a plain structure composed of set of attribute-value pairs as X= {X1, X2..... Xn, Xc }
b) Where, X1, X2 .....Xn are the input attributes and a set of solution Xc i.e. Output attributes
c) *Case – base*: The case base is a database of solutions to previous problems and it is the foundation of every part of the process of augmentation.
d) *Case indexing*: A good indexing of the cases in the case- bank allows only relevant cases to be retrieved. Without indexing the retrieval time will become large because it has to test to each case of the case-base for similarity measure.
e) *Case retrieval and adaption*: Case retrieval is the process of selecting part solved case that best match the present problem or new case. Case adaption is the process of adjusting similar case in the case base to form the selection of new case.
f) *Learning:* The learning mechanism is achieved by inserting newly solved cases into the case base.

Algorithm: The algorithm to develop CBR model for voltage security assessment is given below.

Step 1: A large number of load pattern are generated randomly by perturbing the real and reactive loads at all the buses.

Step 2: A CPF method is performed for all the load patterns to calculate the maximum loadability margins in terms of real power margins for each line outage.

Step 3 : Cases are represented by feature weight vectors consist of real and reactive loads at all the load buses and corresponding security class in the output. A separate set of cases is generated for each line outage and an additional feature i.e. line outage member 'K' is introduced into a weight vector representing a case.

Step 4: Case-base is organized for each line outage in different groups separately. All the cases corresponding to each line outage is stored in their respective groups.

Step 5: When a new case is presented to the CBR system, it is directed to the respective group of cases into the case- base.

Step 6: Determine the most similar case to the new case from case base using step 3.

Step 7: The output class corresponding to the most similar case from step 6 is assigned to the new case.

Step 8: All the feature values of the new case are compared with most similar case found in the step6.If all the features are matching exactly, then this case is not included into the case bank, otherwise included into case base for future use.

As the computation time is concerned, CBR is very much faster than load flow study and other analytical methods. CBR is most useful for on-line VSA at energy management system [68].

VI. Artificial Nueral Network Based Model

In ANN based model there are 10 researchers have done analysis by using various techniques .There are some following techniques given in Table II. The security criteria of a power system require that branch power flows and bus voltages are within their limits, not only in normal operating conditions but also when any credible contingency occurs [99,100].

TABLE II

Sr. No.	Techniques used	Total paper	Paper No.
1.	Clustering Technique	1	101
2.	Fuzzy Logic	1	35
3.	Fuzzy PSHNN	1	36
4.	RBFN	1	37
5.	Bayes Classifiers	2	38, 39
6.	Ward Equivalent	1	40
7.	Layered feed forward NN	1	41
8.	Back propagation	1	99
9.	Counter propagation	1	100

VII. Simulation Models

A variety of simulation models and tools used for VSA in power system. In simulation model solution is found using algorithm that consider the physical phenomenon that governs the process. Simulation method establishes mathematical model and solve them for VSA. In VSA some simulation methods which are directly associated with the security constraints used in optimal load shedding by means of continuation power flows (CPF) [42,43,49,51] as well as maximum loadability optimal power flows (OPF) [43,44,51] are discussed in detail, some researchers also describes a "standard" security constrained (SC) OPF auction [45,46,51] as well as two recently proposed voltage stability-constrained (VSC) OPF-based techniques [51] used to better represent security limits in market clearing and power dispatch techniques.

VIII. RESTRUCTURED ELECTRICITY MARKET

Restructuring of electric power industry is an issue related to generation, load and transmission. Transmission security is closely associated with transmission congestion; accordingly security cots will represent the cost of congestion relief. But in the deregulated environment, with the increasing complexity of potential transactions the impact on system and market operation caused by congestion management needs to be carefully investigated because it bridges economic and security concerns in electricity marked [89]. There are several methods calculate the pricing [93] power system economics, power system reliability[86], zonal pricing by using sag energy index [87], price forecasting in deregulated market [88], etc. All these methods used OPF by using voltage security constraints.

In deregulated power system, real power is usually dispatched first in the energy market. Then system operator determines reactive power dispatch for system security. However in real system, it technically impossible to decouple real & reactive power completely since the reactive power dispatch may influence the real power dispatch. To overcome this problem, the real & reactive power optimization is integrated. This approach minimizes the combined total MW and MVAr generation cost, while maintaining the minimum specified VSM along with after operational constraints [92].

Spanish Electricity Market [82, 81, 88], Ontario Electricity Market [84], which has caught the attention of most of the researchers. These are based on standard market design structure which is basically two-settlement structure or single –settlement real-time structure.

IX. CONCLUSION

In this paper classification of VSA has been done on the basis of i) Contingency analysis ii) Decision tree (DT) iii) Phase Measurement Unit (PMU) iv) Case Based Reasoning (CBR) v) Neural Network based methods vi) Simulation Methods vii)Restructured Electricity Market. There is no bench mark for checking the continued out-performance of a single model over other models. Most of the results reported by different researchers cannot be put in a single framework because diversity in their presentation. Here the various views of researchers for VSA has been assembled during the year 2000 to 2013. This allows the user for deep assessment of voltage security.

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