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Optimal PMU Placement for Voltage Security Assessment using Decision Tree Algorithm

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Abstract: One application that is gaining attention in today's deregulated market is the improvements that PMUs offer for real-time congestion management. Installing PMUs for full system observability is a large investment. The strategy used should be practical, adaptable, and cover the entire process from preparation to installation schedule. The three issues addressed in this paper placement model, placement algorithm, and simulation and result cover the entire process. The objective of optimal PMU placement problem is to install minimum PMU to ensure full observability of the power system. This paper deals with the decision tree algorithm for optimal placement of PMU for voltage security assessment.

Keywords: Decision Tree, Machine Learning, Phase Measurement Unit, Security Assessment, Voltage Security

1. INTRODUCTION

The phasor measurement unit (PMU) has the potential to revolutionize the way electric power systems are monitored and controlled. This device has the ability to measure current, voltage, and calculate the angle between the two. Phase angles from buses around the system can then be calculated in real time. This is possible because of two important advantages over traditional meters – time stamping and synchronization. Monitoring real-time angle differences has many potential applications in power systems. placing PMUs in various substations can help prevent blackouts by real-time monitoring by system operators. System operators can be warned of potential problems more quickly during critical situations, where seconds can make all the difference in detecting and dealing with dangerous cascading events. If a cascading problem were to arise, PMUs would be very useful in determining where and how to perform system separation to limit the effect of the system disturbance.

The GPS time pulses make it much easier to see what happened when and where, even across systems with different SCADA systems and state estimator time delays.

PMUs can also improve system models when the data is analyzed offline[1]. Time synchronized recording of how a generator or other systems react after a series of actions can be used to improve existing models or create new ones. It ensures PMUs from different manufacturers operate well together. Initial cost of PMUs in the early 90's was about $20k. The price has since dropped to $3k for the simplest units. However, installation costs remain high, between $10k-50k depending on the utility and location. To make system economical and reliable this paper deals with the approach for optimal PMU placement by using machine learning decision tree algorithm for the voltage security assessment of power system network.

The decision tree may be divided into the classification and regression trees[7]. As the output variable, the former deals with qualitative one while the latter handles quantitative one. Most of the studies on applications of the decision tree to power systems are based on the classification tree. The reason why they focus on the classification tree is that the classification application is easier to handle than the regression one.

Indeed, the regression tree itself does not work so well and need some techniques that supplement the function. In this paper a decision tree approach is proposed for optimal PMU placement for on-line voltage security assessment [4]. In the proposed method only one decision tree is trained to assess voltage security. This merit results the total training time to decline. It also reduces the required time for on-line operation of the trained tree.

2. PROPOSED SCHEME

An on-line voltage security monitoring system using decision trees (DTs) model that accepts real-time direct measurements from PMUs to predict voltage security status. Both DTs and PMUs satisfy speed requirements to give operators ample time to do preventive or corrective control actions given a potentially risky voltage collapse situation.

2.1 OPTIMAL PLACEMENT OF PHASOR MEASUREMENT UNITS

A novel methodology for optimal placement of PMUs in a power network is proposed. The variable importance derived from CART was utilized to rank the importance of network substations for stability assessment applications. The performance of DTs using synchrophasor measurements from a limited number of PMUs was checked. The Tree were fed with voltage and current phasors measured at all buses. An underlying assumption is that almost every substation is equipped with a PMU. In practice, this is not economically feasible since the installation of PMUs and corresponding telecommunication path is very costly. A reasonable approach may be to install only a limited number of PMUs at the most critical substations.

2.2 SYSTEM ACCURACY

A classification tree has been developed in CART using 70% of the cases, and the rest 30% has been used in new case testing. The classification accuracy is evaluated as follows.

ACCURACY = NUMBER OF CORRECT PREDICTION/ TOTAL NUMBER OF PREDICTION (1)

The DT accuracy is summarized in Table I and Table II . It is observed that an overall prediction accuracy as high as 99.06% and 96.88% has been achieved for IEEE 30 and IEEE 39 bus system respectively. The use of Decision Trees for online stability assessment without the knowledge of system model parameters has been listed in this work:

• The scheme is a measurement-based method that complements the traditional model-based approach. It is particularly useful when system model parameters are not readily available;
• This approach is able to provide control center operators with real time support by making use of the quickly updated PMU measurements;
• Once trained using the knowledge base, the DT-based predictor can achieve high accuracy in online oscillatory stability estimation;
• The data mining tools are capable of reflecting the evolving system operating conditions when the most recent PMU measurements and corresponding knowledge base are used when the results are compared with other data mining tools such as ANN and SVM, it is observed that almost identical prediction accuracy can be achieved[5].

3. VOLTAGE SECURITY

Voltage security evaluation is an assessment if the system meets the voltage security criteria when subjected to these contingencies. Voltage security enhancement consists of operator initiated preventive and control actions to create sufficient margin if the voltage security criteria is violated[11][12]. Voltage stability indices indicate how far an operating point is from voltage instability. Voltage security (VS) is the ability of the power system to maintain voltage stability following one of the lists of "credible events." A credible event could be a line or generator outage, load ramp, or any other event stressing the power system. Voltage security analysis associates the current system conditions to its voltage security status[4]. The system condition is characterized by its state (complex bus voltages) or parameters calculated from it such as real and reactive flows, active injections, etc. VS status could be secure or insecure. If a system is insecure, preventive action must be initiated to reinstate voltage security. Preventive action includes capacitor-switching, generator re-dispatching, locking of tap-changer, etc. If the system is secure, useful information is its distance from voltage insecurity. "Distance" here could be in terms of quantities such as total system load, or tie line flows. The voltage stability indicators could be used to determine the real time voltage security status. Speed must be a primary consideration however to leave more time for operators to react. Accuracy is another requirement although it is affected by numerous factors such as 1) direction of stress, 2) initial operating point, etc

3.1 Voltage Security Monitoring Using Decision Trees

Decision trees (DT) models were chosen to carry out the classification function of the on-line voltage security monitoring system. Decision trees belong to a class of "Automatic Learning" techniques used to derive information from database. The reliability of a decision tree is a measure of the robustness of its classification ability on a separate test data set. A decision tree partitions the input space of a data set into mutually exclusive regions, each region being assigned a label or a value. Within the context of voltage security assessment, we can have two types of trees[2]:

1. Classification type – classifies an operating point as "secure" or "insecure" based
on a pre-defined voltage security criterion; and
2. Regression type – associates an operating point with margin to collapse

This reliability is expressed as the ratio of misclassified cases to the total number of test cases submitted to the decision tree. A method exists to find the "right-size" tree, which is that DT with the highest reliability. It involves generating the maximum possible sized tree during the node splitting process, and then pruning back this big tree by eliminating its weakest links Decision trees are fast and efficient models to the voltage security monitoring function. Only rules or tests arranged in a binary tree like fashion are used and there are no floating-point calculations. Decision trees blend naturally with fast measuring capability of PMUs.

Fig.1. shows a classification type DT for voltage security monitoring. A real time measurement vector is dropped down the root node of the tree.Depending on the result of this test the measurement vector will "drop" down into one child node, wherein another test is made, and so on. The classification process stops when the measurement vector settles into a terminal node. A terminal node has a voltage security class pre-assigned to it during the tree building process. The voltage security class of the terminal node

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(where the real-time measurement vector will finally lie) will then be the voltage security class of the current operating condition as characterized by the measurement vector.

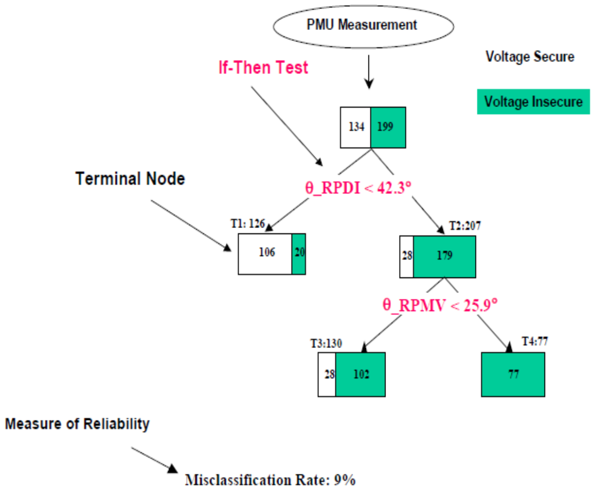

Fig 1. Classification-Type Decision Tree for Voltage Security Monitoring

3.3 Data Generation

Decision trees require training points encompassing realistic operating conditions, in terms of load, generation mix, and outages. The credible outages encompass single (n-1) and double (n-2) outage contingencies on 765 kV, 500 kV, and 345 kV systems. The500 kV line outages are externally located from the study region The contingency list also includes single unit outage of the selected power plants .The next step is to assign a margin to voltage collapse for each of this operating point. Here we have adopted the theory linking voltage collapse to saddle-node bifurcation [6] . At the saddle point, the system loses a stable operating point and the ensuing dynamics leads to voltage collapse .We used a power flow model and the method described in to calculate the critical point (the knee) of the P-V curve.

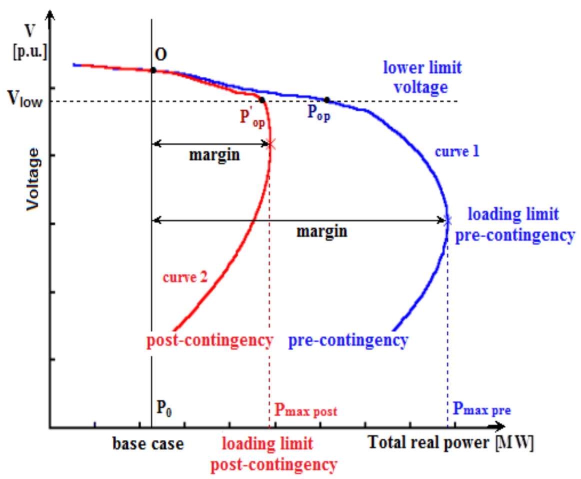

Fig.2. Determining the Nose of the PV Curve Using Successive Power Flow

Simulations for pre contingency and post contingency case

3.4 Loadability Margin

In order to identify voltage instability and to predict the maximum loadability of a power system the load margin at bus i, denoted by PMi, is defined to be

$$P_{Mi} = P_{maxi} - P_{0i} \qquad (2)$$

where P0i and Pmaxi are the current operating value of real power and the maximum deliverable power at bus i, respectively.

3.5 Voltage Security Criterion

Determining the voltage security criterion is another important aspect. This is equivalent to assigning a class (secure or insecure) to an operating condition [13]. There is not a universal approach to voltage security classification however. Nonetheless, we impose the following conditions that must be met for the study system to be voltage secure:

1. Minimum operating voltages at identified power plants.
2. A margin to voltage collapse of 70% of base case peak load.

4. SIMULATION AND RESULT

According to the proposed algorithm in section 5, simulations have been conducted on IEEE 30-bus and IEEE 39- bus networks. The networks schematic is represented in Fig.3. & Fig.4. .

For the simulation purpose the power flow operation has been conducted using MATLAB software. In this paper the threshold for voltage security assessment has been evaluated.

Those states corresponding to loadabilty margin and they are categorized as “secure” and “insecure”. The security/insecurity threshold is taken as 0.42 .The simulation procedure is operated for single contingency situations. The simulation result is given in the Table I and Table II for the IEEE 30- bus and IEEE 39 –bus network respectively. In this paper, line outage is considered as contingency.

After testing the trained decision tree, the results have been used for evaluating decision tree performance. According to the simulation results the performance index accuracy has been calculated. The best PMU places have been determined based on the trained decision trees.

The PMUs that appear on the higher stages of the decision tree show the optimal PMU places. A sample decision tree, obtained from the simulation results, is presented in Fig. 5.and Fig.6.

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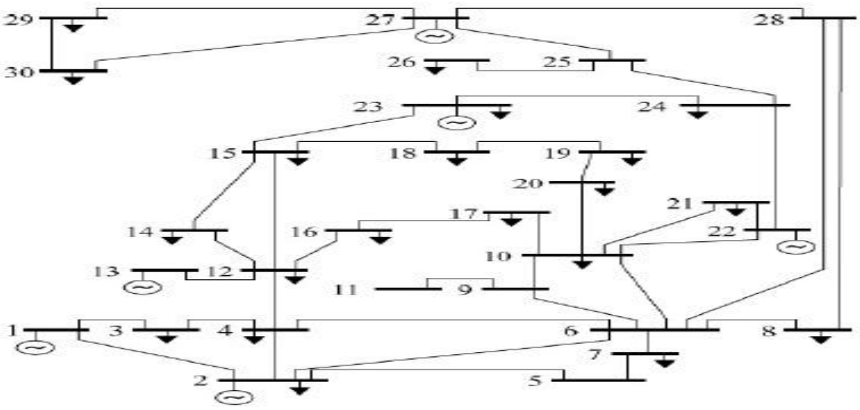

Fig.3.IEEE standard 30 bus system

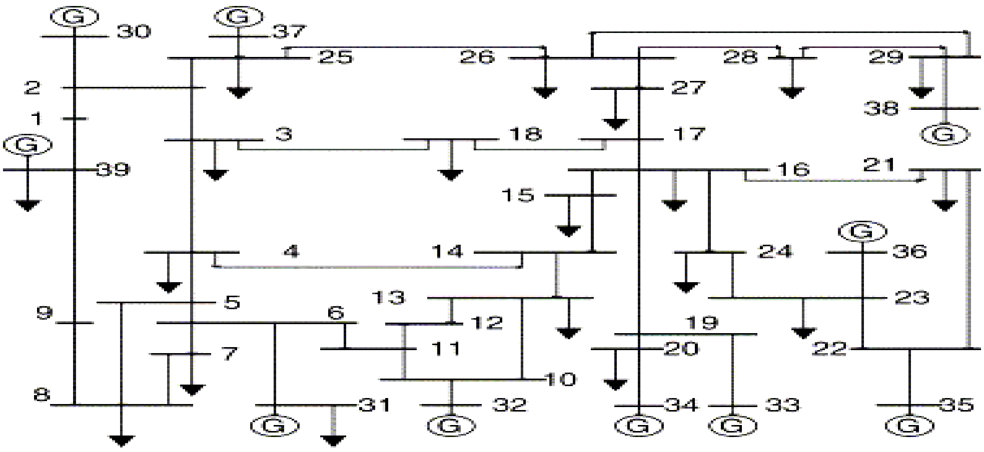

Fig.4.IEEE standard 39 bus system

TABLE I DT ACCURACY CHART FOR IEEE 30 - BUS NETWORK

S.N	TOTAL USED BUSES	BUS LOCATION	ACCURACY(%)
1	3	2,3,5	97.49
2	4	2,3,5,24	97.87
3	5	2,3,5,24,18	97.99
4	6	2,3,5,24,18,19	98.4
5	7	2,3,5,24,18,19,7	98.43
6	8	2,3,5,24,18,19,7,8	98.45
7	9	2,3,5,24,18,19,7,8,16	98.59
8	10	2,3,5,24,18,19,7,8,16,12	98.74
9	11	2,3,5,24,18,19,7,8,16,12,30	98.76
10	12	2,3,5,24,18,19,7,8,16,12,30,21	98.81
11	13	2,3,5,24,18,19,7,8,16,12,30,21,17	98.88
12	14	2,3,5,24,18,19,7,8,16,12,30,21,17,23	98.89
13	15	2,3,5,24,18,19,7,8,16,12,30,21,17,23,15	98.92
14	16	2,3,5,24,18,19,7,8,16,12,30,21,17,23,15,26	98.93
15	17	2,3,5,24,18,19,7,8,16,12,30,21,17,23,15,26,29	98.95
16	18	2,3,5,24,18,19,7,8,16,12,30,21,17,23,15,26,29,14	98.96
17	19	2,3,5,24,18,19,7,8,16,12,30,21,17,23,15,26,29,14,4	98.97
18	20	2,3,5,24,18,19,7,8,16,12,30,21,17,23,15,26,29,14,4,20	99.05
19	21	2,3,5,24,18,19,7,8,16,12,30,21,17,23,15,26,29,14,4,20,10	99.06
20	ALL BUSES	ALL BUSES	99.0097

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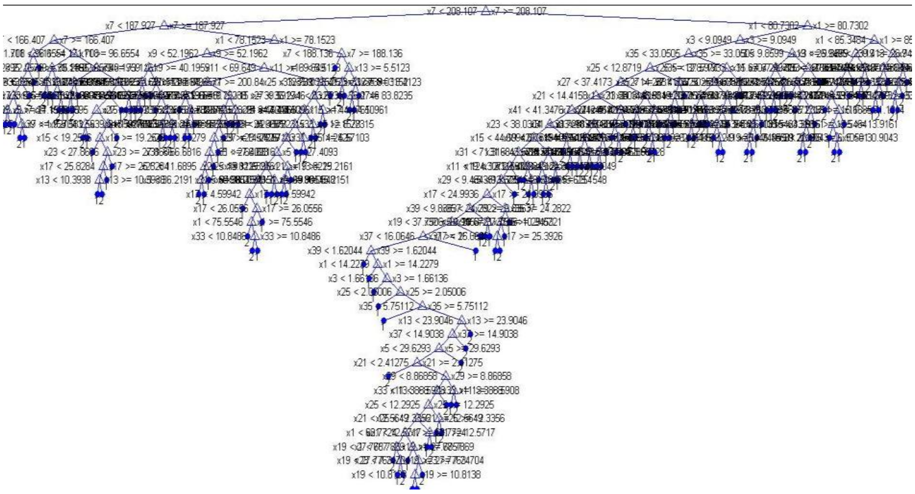

Fig.5. .DT FOR IEEE 30 BUS SYSTEM

TABLE II DT ACCURACY CHART FOR IEEE 39- BUS NETWORK			
S.N	TOTAL USED BUSES	BUS LOCATION	ACCURACY(%)
1	3	4,8,12	92.71
2	4	4,8,12,15	93.62
3	5	4,8,12,15,20	94.54
4	6	4,8,12,15,20,24	95.04
5	7	4,8,12,15,20,24,39	95.49
6	8	4,8,12,15,20,24,39,9	95.91
7	9	4,8,12,15,20,24,39,9,31	96.24
8	10	4,8,12,15,20,24,39,9,31,23	96.53
9	11	4,8,12,15,20,24,39,9,31,23,29	96.54
10	12	4,8,12,15,20,24,39,9,31,23,29,27	96.55
11	13	4,8,12,15,20,24,39,9,31,23,29,27,3	96.56
12	14	4,8,12,15,20,24,39,9,31,23,29,27,3,7	96.61
13	15	4,8,12,15,20,24,39,9,31,23,29,27,3,7,25	96.67
14	16	4,8,12,15,20,24,39,9,31,23,29,27,3,7,25,18	96.69
15	17	4,8,12,15,20,24,39,9,31,23,29,27,3,7,25,18,1	96.73
16	18	4,8,12,15,20,24,39,9,31,23,29,27,3,7,25,18,1,21	96.75
17	19	4,8,12,15,20,24,39,9,31,23,29,27,3,7,25,18,1,21,28	96.82
18	20	4,8,12,15,20,24,39,9,31,23,29,27,3,7,25,18,1,21,28,16	96.88
19	21	4,8,12,15,20,24,39,9,31,23,29,27,3,7,25,18,1,21,28,16,26	96.89
20	ALL BUSES	ALL BUSES	96.84

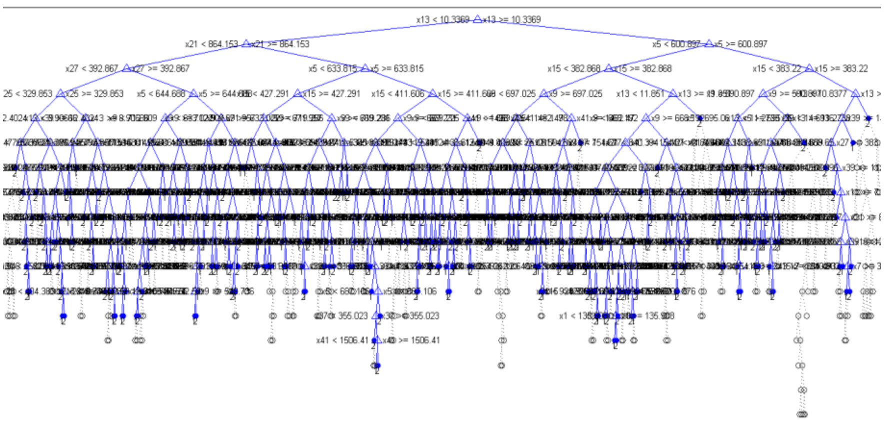

Fig.6. DT FORSYSTEM IEEE 39 BUS SYSTEMS

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5. CONCLUSION

The decision tree based method has been used in this paper for voltage security assessment and optimum PMU placement. Simulations results show the high efficiency of this method. The accuracy has been calculated for each possible cases for PMU placement location .According to the simulation results the proposed method has acceptable performance indices and a great capability for voltage security assessment. From the Table (I)and Table (II) it is observed that for the lesser number of PMU placement we got the almost similar system accuracy hence lesser number of PMU placement has to be preferred for the economical system and It should be noted that decision making for security assessment is independent of input variables. So the size of the input data can be reduced and subsequently the decision making process will be less time consuming.

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