Power System Security Evaluation and Preventive Control using Classification and Regression Tree

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Abstract: -This paper presents a Decision Tree (DT) Based method for online security evaluation of power system. The proposed method uses CART algorithm to generate a security classifier in the form of a decision tree using a data set of plausible operating condition. The generated DT classifier is then used for on line security assessment of power systems. The method has been applied on an IEEE test systems and the results have been reported.

Key-Words: - Power system security, Decision tree (DT), CART, Entropy, Gini index, Class probability

1 Introduction

Power system security evaluation is an important aspect of modern power systems. Due to competitive business environment, the stress of modern electric utilities is to ensure reliable, uninterrupted and economic power supply to the consumers. This entire requirement has forced modern electric power industries to extract maximum benefits of the available resources. As a result modern power systems are operating under stressed operating conditions and closer to their limits. Under such conditions even a small disturbance, if not taken care of, could endanger power security and may lead to system collapse with consequent interruption in power supply and loss of economy. Therefore, there is a pressing need to develop fast on line security monitoring methods, which could analyze the level of security and suggest possible control strategy to ensure reliable and uninterrupted power supply.

A complete answer about power system security requires evaluation of transient stability of power systems following some plausible contingencies. Several method for fast transient stability evaluation have been proposed in the past by adopting namely direct methods, pattern recognition (PR) technique, Decision Tree (DT) method and Artificial Neural Network (ANN) approach[1-5].

This paper presents a DT method for on-line security evaluation and preventive control of power system. In this method, CART algorithm [6-8] has been used to generate DT classifier which takes only a few system parameters to predict system security and to provide necessary preventive control strategy. The method has been applied and tested for its applicability and effectiveness on IEEE 57 bus system.

2 The DT Methodology

The proposed method uses DT as a classifier which classifies an operating state of a power system into 'secure' or 'insecure' class under a predefined contingency set. The DT classifier is generated using an off-line data set, which is generated by the most accurate power system solution methodology. The complete description of DT methodology is beyond the scope of this paper and can be referred [6-8]. Nevertheless, it is important to discuss the basic design procedure, which involves the following steps:

1. Attribute selection 2. Data set generation 3. DT building algorithm 4. Performance evaluation.

The attribute selection is an important step. The guiding principal for the choice of attribute set is to select those system variables which are monitorable, controllable and which adequately characterized an operating state of a power system from security classification point of view. C. M. Arora and Surana [9, 10] have derived that the real and reactive power generations of generators carry sufficient information about the class of system security (secure or insecure system security. This fact is also supported by the outcome of the research paper [3]. Therefore, the proposed initial feature set consists of pre-disturbance real and reactive power generation of each generator.

The second step in the design of DT classifier is data set generation for the classifier training. The primary objective of data set generation is to obtain a sufficiently rich data base containing plausible operating states of power system. To generate a data set, initially a large numbers of load samples are randomly generated in the typical range of 50 to 150 percent of their base case values. For each load sample (load combination) optimal power flow (OPF) study is performed to obtain steady operating state. A disturbance (fault), from a predefined set of contingency, is simulated for a specified duration of time. Using dynamic stability studies, load angle trajectories of all generators is computed and plotted over a period long enough to ascertain system stability under the specified disturbance. Similarly for each of the disturbances from the contingency set dynamic simulation is performed to ascertain system stability under the corresponding disturbance. For carrying out dynamic simulation, numerical integration techniques is used as it has the flexibility to include all kind of modelling sophistication and thus is able to provide desired degree of accuracy. If a steady state operating point is found to be stable, for all disturbances of the contingency set, the operating state is assigned "secure (0)" class label else it is assigned "insecure (1)" class label. During data set generation some operating states are also generated in the neighbourhood of optimal dispatch to ensure inclusion of all realistic operating states. Some frequent topological changes may also be considered during data generation.

To generate the DT classifier commercially available CART software has been used [11]. The aim of CART is to construct an efficient piece-wise constant estimator of a classifier from a learning set. This classifier is in a form of a tree. The tree is structured in top-down fashion consisting of various test and terminal nodes. Each test node is associated with an optimal splitting rule and a subset of the Learning set (LS). A terminal node is a class pure node. A built tree is, thus, a hierarchical organization of the LS into a collection of subsets. The most general subset is the LS itself and corresponds to the top (root) node of the DT. Starting from the root node, at each level of the DT, the corresponding subsets are partitioned on the basis of some optimal splitting rules. These rules are in the form of "if- then-else" rules. The lower is the level, the more refined is the corresponding partition. Therefore, generating successors of a given non-terminal (test) node amounts to reducing the uncertainty about the classification. To split a given node (subset), the CART algorithm makes use of impurity functions such as Gini-Index, Entropy and Class-probability based impurity functions. The particular choice of the splitting criteria depends on the problem in hand.

3 Simulation and Results

To investigate the effectiveness of the proposed method a study was performed on IEEE - 57 bus system. The system consists of 7 generators, 57 buses, 67 transmission lines, 18 transformers and 42 loads. The diagram of the system is given in [12] and the data were taken from [12, 13]. It is assumed that contingency set contains only one disturbance, which is a 3-phase fault on the 400kV transmission line connecting buses 8 and 9, near bus 9. Duration of the disturbance is assumed to be 210 ms, which is cleared by opening the line at both the ends. By varying the loads randomly from 50% to 150% of their base case values a data set have been generated. The data set consists of 1000 operating states with fixed system topology.

Since the there are 7 generators in the system therefore attribute set consists of the 14 attributes (features) namely PG_1, PG_2, PG_3, PG_4, PG_5, PG_6, PG_7, QG_1, QG_2, QG_3, QG_4, QG_5, QG_6 and QG_7. However, during data generation it has been found that generators 2, 3, 4 and 6 are always operating at their upper active power generation limits and so corresponding features carry no discriminating information about system security. Therefore these features can be ignored. Thus the attribute set consists of following 10 features:

$A = [PG_1, PG_5, PG_7, QG_1, QG_2, QG_3, QG_4, QG_5, QG_6, QG_7]$

By applying CART algorithm on the learning set of 500 load samples of fixed system topology 3 different DT classifiers have been generated as shown in the Fig. 1, Fig. 2 & Fig. 3.

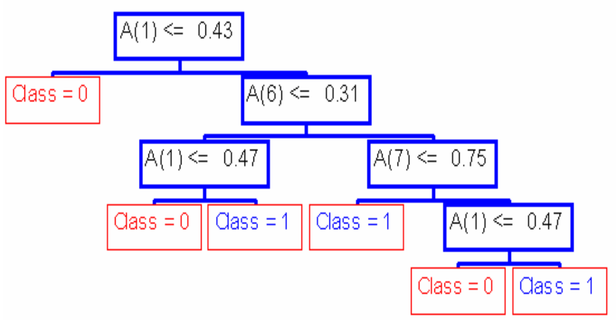

Fig. 1: Tree generated using CART (Gini-Index)

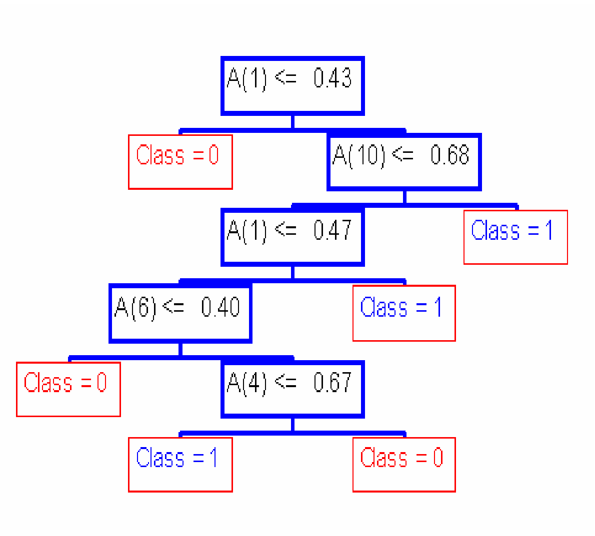

Fig. 2: Tree generated using CART (Entropy)

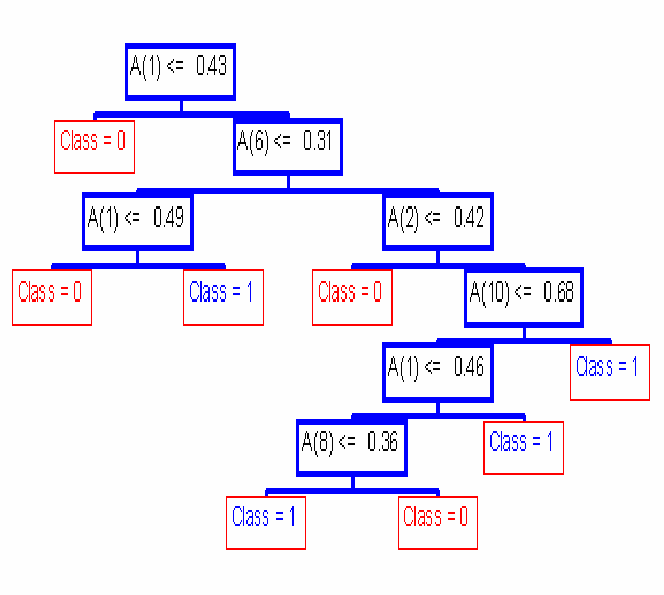

Fig. 3: Tree generated using CART (Class Prob.)

Each block of the non terminal nodes defines an optimal splitting rule in the form of

A(i) <= threshold value?

Here *A(i)* is the i^{th} feature.

The test results of the classifiers on a test set of 300 load samples are summarized in Table 1. The result shows that entropy based classifier gives better accuracy.

To investigate the effect of the size of training set on performance of DT classifier 5 different set of DT classifiers have been generated using 5 different training set and the corresponding test results are summarized in Table 2. The error versus size of training set curve is shown in figure 4.

Table 1

Impurity Function	No. of Nodes	Percentage test set Error
Gini-Index	11	3.91675
Entropy	11	3.666
Class Prob.	15	4.16675

Table 2

Training Set Size	Percentage test set Error		
	Gini-Index	Entropy	Class Prob.
300	5.7335	6.23225	5.698
400	4.85875	5.27375	4.85875
500	4.68125	4.73075	4.731
600	4.1875	3.6875	4.25
700	3.91675	3.666	4.16675

From the results it can be observed that for smaller training set size the entropy based splitting criteria gives poor accuracy rate as compared to the gini-index based and class-probability based criteria. However when the size of available training set is large the entropy based classifier gives better accuracy rate as compared to the others.

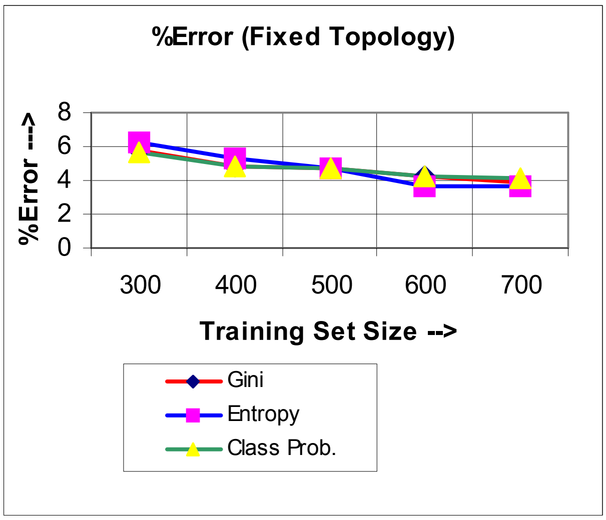

Fig. 4: % Error versus Training Set Size curve

4 Conclusion

The transient security evaluation of modern power system is becoming a major concern for on line operation. This paper investigates the potential of CART algorithms for on-line security evaluation and preventive control of power system. The results obtained on IEEE 57-bus system show that the CART based DT classifier are able to predict system security with a high degree of accuracy. The effects of various CART design parameters have also been investigated. It is found that in general a DT classifier requires a large training set and entropy base splitting criteria is the most suitable criteria for security evaluation using DT classifier. The DT approach provides preventive control strategy in term generation re-dispatch alternatives. The choice of appropriate preventive control action would depend upon the feasibility and economic aspect of the preventive control solutions provided by the DT classifier. The approach can be generalized to handle multi-contingency security assessment under varying topological conditions.

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