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Online Decision Tree based strategy for power system static security margin improvement using wind farms

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ABSTRACT

In this paper wind farms (WFs) are used to improve the security margin of power system. Feature extraction method is used to save all features effect on the security of power system. The proposed method is implemented on IEEE 39-bus network and the results show its effectiveness on the static security margin. It should be mentioned that the proposed method can deal with correlated random variables.

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Introduction

High penetration of distributed energy resources in networks encourages the operators to use them to control the states of the power system. Among renewable energy resources, wind energy is well used and has a major role in the providing electrical energy in all over the world. One of the main issues in power system is the security of network.

The security is an important issue for utility engineers and researchers [1–14]. Some of the researchers have been used numerical method to assess the security of the power system. In numerical methods [2–4], a non-heuristic method is used. In other hand, some of the researchers have been used machine learning methods and different classifiers to assess the security of power system [5–14]. In machine learning based methods, a database is built, and then the database is used to train a classifier. In [5–7] Decision Tree (DT) has been used as classifier. In [5] a boosting technique has been used to improve the ability of the classifier. In [6] DT has been used to analysis the parameters impact and one index named as Transient Stability Estimation Index (TSEI) has been presented. In [7] Principal Components Analysis has been used for feature extraction. In [9–11] Radial Basis Function (RBF) has been used as classifier. In [10] a wavelet based method has been proposed for feature extraction. In [12] Artificial Neural Network (ANN) and in [13] Support Vector Classifier (SVC) has been used as classifier. Different feature selection and feature extraction [12] algorithms have been applied to machine learning based methods. In these methods, independent random variables have been used to build the database, but in the real networks, there is a correlation among the generations and loads, i.e., in peak hours almost all the buses have their peak consumption. In this paper, a new method is used to overcome this problem.

Improving the security margin of power system is an interesting subject in literatures. The different methods have been proposed in this subject [15–19].

The difference among these methods lies in the selecting strategy for generator selection and selecting the loads to be shed. In [18,19] a feature selection method has been used to choose the most effective generators. In [20] the Decision Tree (DT) has been used to add some constraints to the problem of Optimal Power Flow (OPF). In [21] the pattern discovery method has been used to add some constraints to the OPF. In [18] the feature selection method has been used to select the most effective loads.

The maintenance cost of conventional generators increases, when the oscillations of output power of generators increase, and also the life time of generators decreases. Using green energy resources to control the states of power system become more interesting for system operators. In this paper, the wind farms are used to improve the security of the power system. The output of WFs set to the highest possible value. So, the output of WFs can

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only decrease. To decrease the output power of the WFs, some wind turbines falls out or the converter set points are changed.

The novelties and contribution of this paper are as follows:

- Using wind farms to improve the margin of static security.
- Using Nataf transformation to generate random correlated data for security assessment purpose.
- Proposed Decision Tree based algorithm to improve the static security margin.
- Using Nataf transformation, DT and PCA in one static security margin algorithm is presented for the first time in this paper.

This paper is organized as follows. In Section 'Proposed method', the proposed method is introduced. In Section 'Case study', Simulation results and the case study are presented and finally conclusion of the paper is presented in Section 'Conclusion'. Nataf transformation and Principal Components Analysis (PCA) are explained in Appendix A.

Proposed method

In this paper, the proposed algorithm is based on classifiers. Among different classifiers, The DT is selected, because of it's characteristics. DT divides the feature spaces to separate subspaces, with some simple if-then rules.

In [3–14] random variables, for loads and generation of different buses, have been built for different scenarios. In these papers, no correlations among variables have been considered. In a real network, there is a correlation among different loads and generations. In addition to loads and generations, the adjacent wind farms have correlated outputs, too. In the proposed method, the correlation between variables are modeled with Nataf transformation. This transformation is introduced in Appendix A.

The next step, after the generation of database, is the selection of features to train the classifiers. There are a lot of features which have been used in literatures. Different feature selection methods have been used to select the best features for assessment of security of power system.

In this paper, one of the famous method of feature extraction is used. In feature extraction methods none of the features have been eliminated. The features have been mixed together and built new features. In the proposed algorithm, the effect of all the input features of the classifier is important on the security of power system. Principal Components Analysis (PCA) is used in this paper. PCA is introduced in appendix. By the extracted features the security of power system has been assessed. The number of extracted features is selected by sensitivity analysis. Active and reactive power of each bus is used as the input features of the classifier. The DT is trained by the extracted features of database, and divide the feature to subspaces. Some of the subspaces are "secure" parts and the others are "insecure". The trained DT classifies the security state of the power system.

In the proposed algorithm, some preventive actions should be applied for the scenarios which falls into "insecure" parts. In this paper generation rescheduling is used as the preventive control of security of power system. In this paper, two strategies are used for generation rescheduling. The strategy 2 is a backup for strategy 1.

Strategy 1: In this strategy the Distributed Energy Resources (DERs) are used to improve the security margin of power system. Due to high penetration of DERs, they can also be used for system security improvement. The DERs are used in substitute of conventional generators, in order to reduce changes of the output powers of those generators, and also their maintenance cost [22]. In this paper, Wind Farms (WFs) are used to improve the security margin of power system.

Usually, the operators of networks, set the output of WFs to the highest possible value. So, the output of WFs can only decrease and for the security improvement, the WFs can only reduce their production. In other hand the conventional generators can increase and decrease their production. So, the reduced power of WFs should be compensated. In the proposed method paper the most effective generator on security of power system is detected. The most effective generator beside the WFs is used to improve the security of power system.

In strategy 1, the net injected active power of buses, which have WFs, are selected as one of the features to assess the security margin. As shown in Fig. 1, injected active and reactive powers of the remaining buses are reduced by PCA. The final number of the input features is $N+M$, where N is the number of WFs, and M is the reduced number of features. Where x is the number of wind farms, n is the number of buses, which do not have wind farms.

Strategy 2: As it is mentioned, strategy 2 is a backup strategy for strategy 1. It should be noted that, this strategy should be used, when the first strategy is not practical and possible. In this strategy the conventional generators are used to improve the security of power system.

In strategy 2, the net injection active power of buses of the selected generators is selected as security margin index. The number of net injection active and reactive powers of remaining buses are reduced by PCA. The final number of the input features is $N+M$, where N is the number of the selected generators, which should control the security margin, and M is the reduced number of the features.

In both strategies, the feature space has $N+M$ dimensions, which is divided to secure and insecure spaces by DT. The outputs of the DT are if–then rules. These rules divide the feature spaces to different parts. Each part represents a unique class. In this paper, there are two classes, secure and insecure classes.

If one scenario falls into insecure space, the proposed preventive control algorithm tries to move this state from insecure space to secure one. The proposed algorithm, search the feature space to find parts, which the later M features of the scenario are in the margins of that part. In each scenario, some secure parts, satisfying this criterion, are found. One of these parts is selected by minimization of objective function. The objective function is the amount of changes in production of generators. In this method no load shedding is considered to control the security of power system.

To explain the proposed algorithm more clearly, it is assumed that there are one problem with two input features named as "x" and "y", and two output class named as "A" and "B". The feature space based on the DT (Fig. 2) is divided into five areas (Fig. 3).

All of the areas in feature space have specific margins (Table 1). These margins are in the form of intervals for each feature.

For each scenario which is insecure, the algorithm seeks to find some secure areas which the later M features of the scenario are in the margins of that part.

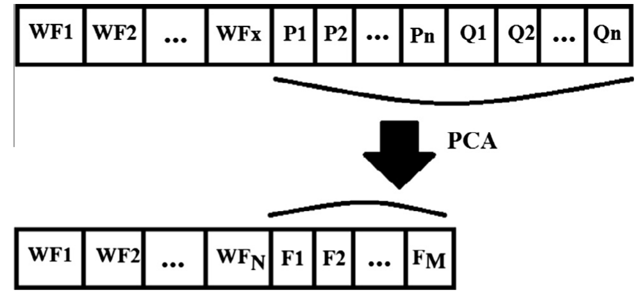

Fig. 1. Feature extraction.

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