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A Fast Fault Detection and Identification Approach in Power Distribution Systems

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***Abstract*—In this paper, a Modified Multi-Class Support Vector Machines (MMC-SVM) technique is developed to simultaneously detect and classify different types of open-circuit faults in power distribution systems. This technique is capable of detecting and identifying open-circuit faults considering the impact of variations in the voltage of different nodes in power distribution systems. The RMS (Root Mean Square) voltage of the power grid is used as the input signal to diagnose the faults. Simulations are carried out on the IEEE 13-node test system considering temporary open-circuit faults in MATLAB software. The simulation results show the accuracy, effectiveness, and robustness of the proposed method.**

***Keywords*—Fault Detection, Fault Identification, Power Distribution Systems, Modified Multi-Class Support Vector Machines (MMC-SVM).**

I. Introduction

Due to the significant increase in electric power consumption, distribution networks carry a large amount of power and therefore, the security and adequacy of power grids should be guaranteed [1-2]. Any disturbances in the generated power by the generation units may cause supply failure and power quality degradation. Reliability, costs of electricity, and protection of power distribution systems are some important criteria which should be taken into considerations by utilities for power system operation and planning objectives [3-5]. Fast restoration of the faulty section, proper operation of protective devices, and precise classification of faults need to be considered to protect power distribution systems [6-9]. Fault diagnosis of power systems can be classified into two groups: (1) Techniques which rely on measuring the line impedance after the fault. (2) Techniques which focus on measuring the generated signal by the fault. Accordingly, continuous monitoring of the voltage, current, impedance, etc. is required for quick restoration of power distribution systems after the fault and it improves the reliability of power networks.

There are numerous research studies conducted on using different techniques for fault detection and identification in power systems. Some knowledge-based techniques of the fault classification in power transmission lines based on Neural Networks (NN) [10-11], Fuzzy Logic (FL), and Fuzzy Neural Networks (FNN) [12-13] are investigated, which all suffer from the complexity of proper training of NN.

Digital Protective Relays (DPRs) are such kind of devices, which measure the voltage and current of the line, send the trip command quickly, and disconnect the faulty line(s). DPRs operate based on sequential components [14] and impedance [15] analyses. Also, Fast Fourier Transform (FFT) [16] and Discrete Wavelet Transform (DWT) [17] are used by the other methods for the fault diagnosis. In order to classify the faults, feature extraction using the information captured by DPRs or Digital Fault Recorders (DFRs) should be performed. The data can be analyzed and supported by Artificial Neural Networks (ANNs) [18], FL [19], Decision Tree (DT) [20], and Support Vector Machines (SVM) [21].

This paper uses a Modified Multi-Class SVM Support Vector Machines (MMC-SVM) approach to detect and identify open-circuit faults in power distribution systems. The RMS (Root Mean Square) voltage of each node in the IEEE 13-node test system, which is simulated and programmed in MATLAB, is used for the fault diagnosis. The raw data is preprocessed by reducing the number of dimensions of features and removing unnecessary and redundant data from data matrices, and therefore, the best features are extracted. The preprocessed data is used for generating the train and test datasets. Accordingly, the MMC-SVM model is trained with the best feature set, and different test sets are tested with the trained MMC-SVM model. The proposed method in this paper not only can quickly detect and identify open-circuit faults in power distribution systems but also improves the accuracy of fault detection and identification significantly and ensures the reliability of power distribution systems.

This paper is organized as follows. The proposed diagnosis technique is presented in Section II. Results and discussions are discussed in Section III. Lastly, Section IV indicates some brief conclusions.

II. Proposed Fault Diagnosis Technique

An MMC-SVM scheme for the estimation of open-circuit fault detection and identification in power distribution systems is discussed in this paper, which is shown in figure 1. In the proposed fault detection and identification technique, the real-time RMS voltage of each node in power distribution systems (as the raw data) is measured. The raw data is classified into two main dataset matrices: (1) Dataset matrix that shows no-fault condition. (2) Dataset matrix that is related to faulty

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conditions. At the preprocessing stage, unnecessary data is removed from the raw data. Then, features are extracted from the preprocessed dataset. From the entire feature set, some of the features cannot predict the output, correctly. Therefore, the prediction accuracy reduces. In order to improve the accuracy of the classification process, redundant features are removed from the dataset. Thereafter, the feature set is normalized, and the train and test datasets are generated. In the next step, the MMC-SVM model is trained based on the Radial Basis Function (RBF) kernel function with the best feature set.

In order to classify the data which is not linearly separable, the RBF kernel function is used for the MMC-SVM model. The RBF kernel equation can be written as follows [22]:

$$K\left(x^{(t_1)}, x^{(t_2)}\right) = \phi\left(x^{(t_1)}\right)^T \phi\left(x^{(t_2)}\right) \tag{1}$$

or,

$$K\left(x^{(t_1)}, x^{(t_2)}\right) = \exp\left(-\lambda \left|\left|x^{(t_1)} - x^{(t_2)}\right|\right|^2\right), \lambda > 0 \tag{2}$$

where K indicates the kernel function, $x^{(t_1)}$ $(m \times n)$ and $x^{(t_2)}$ $(r \times s)$ are the training vectors, respectively. $x^{(t_2)}$ represents the point of reference vector, m, n, r, and s show training vectors dimensions, respectively. $\phi(x)$ is the feature mapping function, and λ is the regularization parameter. Small λ value shows a kernel function with a large variance.

After training the MMC-SVM model, it is tested for the evaluation purposes considering a variety of simulated conditions (faulty scenarios), and corresponding labels for fault detection and identification are predicted, simultaneously. Lastly, the accuracy of fault detection and identification technique is checked separately, as follows:

$$Accuracy = \frac{Accurate\ fault\ classification}{No.of\ test\ samples} \times 100 \tag{3}$$

In addition, the accuracy check is performed based on no-noise and considering white noise (with different levels) conditions, separately. Simulations are accomplished in MATLAB 2018a software on a laptop with Intel Core i7-8550U processor at 1.80 GHz clock speed and 12-GB of RAM.

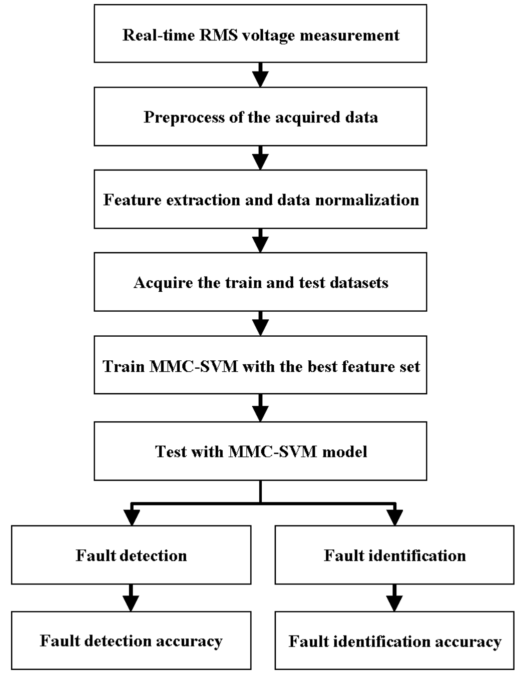

Figure 1. Flowchart of the proposed fault detection and identification technique

III. Results and Discussions

In order to evaluate the performance of the proposed fault detection and identification technique, the IEEE 13-node test system is modeled in MATLAB software, and three types of faults are applied at its different nodes. Then, the RMS voltage before and after open-circuit faults for the entire system is recorded. Fault types are an open-circuit fault at the substation (node 650), open-circuit faults at load centers (nodes 611, 652, 645, 646, 634, 641, and 675), and open-circuit faults in transmission lines (lines between nodes 632-633, 632-645, 632-671, 645-646, 671-680, 671-684, 684-611, 684-652, and 692-675). The simulation is performed for $1\ sec.$, and different fault scenarios are considered for testing the performance of the proposed fault detection and identification technique. Open-circuit faults are applied at different nodes at $t = 0.5\ sec.$ by opening the corresponding breaker(s) connected to each node (and between the lines), and faults are cleared within $0.05\ sec.$ by reconnecting the corresponding breaker(s).

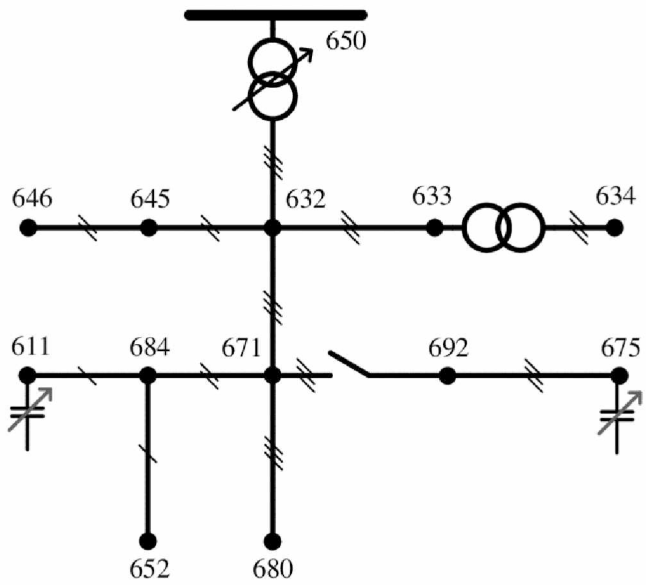

Figure 2. IEEE 13-node test system

Pre-fault and post-fault RMS voltage signals are acquired for three types of faults by real-time monitoring of power distribution systems. The sampling frequency is considered as $60\ Hz$, which is equal to the actual frequency of the power grid. It should be noted that after a series of analysis, it is revealed that choosing $60\ Hz$ as the sampling frequency responds better and generates more accurate results. The complete feature matrix has 15 features. Accordingly, redundant features are removed, and the best features are extracted.

The train and test data matrices are developed considering a variety of simulation conditions, such as pre-fault and all the possible open-circuit faults. To reduce the dependency and sensitivity of the proposed technique to the parameter variations, the train and test matrices are different from each other. Therefore, the total train dataset consists of 756 data samples (20 classes of fault, and one class of pre-fault condition). The test matrix includes 504 data samples (with different combinations).

Different tests are carried out for fault detection and identification. The performance evaluations for fault detection and classification are given in tables 1 and 2, respectively. In these two tables, FS, FL, and FT denote fault at the substation, the fault at load centers, and fault in transmission lines, respectively. It is also observed that by applying the white noise to the original dataset, the proposed method can efficiently detect and identify different faults. However, by increasing the level of white noise (SNR) in the original dataset, the accuracy of the proposed method to detect and identify the fault decreases.

TABLE I. RESULTS OF FAULT DETECTION ANALYSIS

Fault Type	No. of Scenarios	Noise Level (dB)	Accuracy (%)
FL	1	90	100.0
		30	100.0
		20	99.00
		10	96.00
FL	7	90	100.0
		30	100.0
		20	97.00
		10	93.00
FT	9	90	100.0
		30	100.0
		20	96.00
		10	90.00

TABLE II. RESULTS OF FAULT IDENTIFICATION ANALYSIS

Fault Type	No. of Scenarios	Noise Level (dB)	Accuracy (%)
FL	1	90	100.0
		30	100.0
		20	99.00
		10	93.00
FL	7	90	100.0
		30	100.0
		20	95.00
		10	91.00
FT	9	90	100.0
		30	99.00
		20	94.00
		10	90.00

Table 3 shows the overall accuracy of the proposed technique to detect and identify different open-circuit faults. As it is illustrated, the proposed technique can efficiently detect and identify different open-circuit faults.

TABLE III. RESULTS OF FAULT DIAGNOSIS

Fault Type	Detection Accuracy	Identification Accuracy
FS	98.75 %	98.00 %
FL	97.50 %	96.50 %
FT	96.50 %	95.75 %

Compared to the MMC-SVM model which is trained by the linear kernel function, there is a 7% decrease in the overall accuracy of the proposed technique.

IV. CONCLUSIONS

In this paper, a Modified Multi-Class Support Vector Machines (MMC-SVM) technique is proposed and developed to simultaneously detect and classify different open-circuit faults in power distribution systems. For various types of faulty scenarios, the proposed technique gives fast, accurate, and robust fault detection and classification assessments. The uniqueness of the proposed technique is using only the real-time RMS voltage signals of the entire power distribution networks for fault diagnosis. The other important characteristics of the proposed method are collecting a large number of features, applying feature selection method to remove the unnecessary and redundant features and accordingly enhancing the prediction accuracy, considering different faulty scenarios to develop the train and test data matrices, and lastly simultaneously detecting and identifying open-circuit faults. The training time is very short with the proposed MMC-SVM method. The proposed method is tested on the IEEE 13-node test system considering temporary open-circuit faults in MATLAB software. The simulation results reveal the accuracy, effectiveness, and robustness of the proposed method.

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