

Support Vector Machine-Based Fault Detection, Classification and Section Identification Scheme for DC Microgrid



Shankarshan Prasad Tiwari, Ebha Koley, and Subhojit Ghosh

Abstract In recent years, due to the significant development in the industrial and commercial infrastructure, the power demand is growing day by day. The considerable reduction in non-renewable sources of energy and their impact on the environmental pollution due to the emission of carbon has caused rising awareness toward the utilization of green energy resources, i.e., wind, biomass and solar energy sources. However, the integration of the renewable sources has posed serious protection challenges in DC microgrid system. The variation in short circuit level of current in grid-connected and islanded mode makes the protection task more challenging. In this regard, this paper presents a support vector machine-based scheme to perform the task of fault detection and classification, as well as section identification for both modes of microgrid operation, i.e., islanded and grid-connected mode of DC microgrid.

Keywords DC microgrid protection · Support vector machine · Pole to ground fault · Pole to pole fault

1 Introduction

In recent years, the considerable reduction in the availability of non-renewable sources of energy (coal, petroleum products) and the rise in carbon emission has motivated toward the accelerated utilization of renewable resources in power generation. Renewable sources are non-exhaustible, neat and clean sources of energy and hence play a leading role in the reduction of air pollution. The penetration of renewable energy sources in the recent power distribution structure to ensure reliable power

S. P. Tiwari (✉) · E. Koley · S. Ghosh
Department of Electrical Engineering, N.I.T Raipur, Raipur, Chhattisgarh, India
e-mail: shankarshan.tiwari20@gmail.com

E. Koley
e-mail: ekoley.ele@nitrr.ac.in

S. Ghosh
e-mail: sghosh.ele@nitrr.ac.in

with enhanced power quality has led to the concept of the microgrid. A microgrid is a small unit of distributed energy resources, converters and various types of load, i.e., linear and nonlinear load [1]. Based on the type of electrical output power, the microgrid can be classified as AC, DC or hybrid. The development of electronics devices such as mobile phones, LEDs, grinders, savers and other DC power fed equipment has led to the requirement of DC microgrid. In DC system, the power conversion stages are quite less as compared to the AC system, due to which the heat losses are always within the desirable limit, thus increasing the efficiency of the system. The DC system has got numerous advantages over the AC system in terms of efficiency, stability reliability and power transfer capability [2]. With regard to the mode of operation, the microgrid is operated in both modes. The switch at the PCC facilitates the bidirectional power flow. During the islanded mode, the utility grid is disconnected from the rest of microgrid network.

Load variation and occurrence of fault with high resistance in DC microgrid quite often show similar variation in the rate of change of current [3]. On the other hand, during the grid-connected mode, fault current is much higher around 10 to 50 times to that of the islanded mode being 2–5 times. Also, the DER-dependent (inverter and synchronous-based) variation in fault current from the inverter and synchronous-based DERs further makes the protection more challenging [2]. In this context, the present works aim at the development of a microgrid protection with necessary immunity against the diverse operating scenarios and fault levels.

With regard to the protection of DC microgrid, a number of protection methods have been proposed in the literature including, a signal handshaking methods for locating and isolating the faults [4], differential current-based fault detection [5], probe power unit-based protection scheme [6], artificial neural network-based DC microgrid protection [7], SVM-based protection scheme [8, 9], superimposed current-based unit protection scheme [10], wavelet transform-based efficient protection scheme for low-voltage DC micro-grid [11], centralize unit base protection scheme [12], voltage source converter-based over current protection [13]. A common limitation with all these techniques pertains to high-computational complexity arising because of the inclusion of calculations for extracting features from raw post-fault time domain data. In order to develop a reliable and accurate protection algorithm for microgrids with reduced computational complexity, the present work proposes a SVM-based scheme using raw voltage–current data.

2 Test Model of DC Microgrid

The test model of a 350 V DC ring microgrid is shown in Fig. 1 [14]. The DC microgrid system consists of three sources, i.e., PV array, synchronous diesel generator and wind turbine. The test microgrid is simulated in MATLAB/Simulink environment for the implementation of the proposed scheme.

There are six sections, namely A1, A2, A3, A4, A5 and A6 with each section being extended over the length of 1 km. The DERs are equipped with the power conditioning

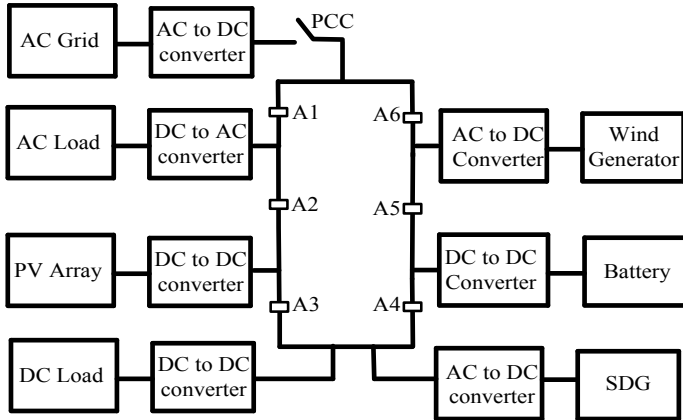


Fig. 1 Test microgrid model of DC microgrid

units with efficient control systems to facilitate the appropriate interface within the microgrid.

To demonstrate the voltage–current profile post-fault in the DC microgrid, a pole to ground fault in section A1 is simulated at $t = 0.3$ s as depicted in Fig. 2. At the

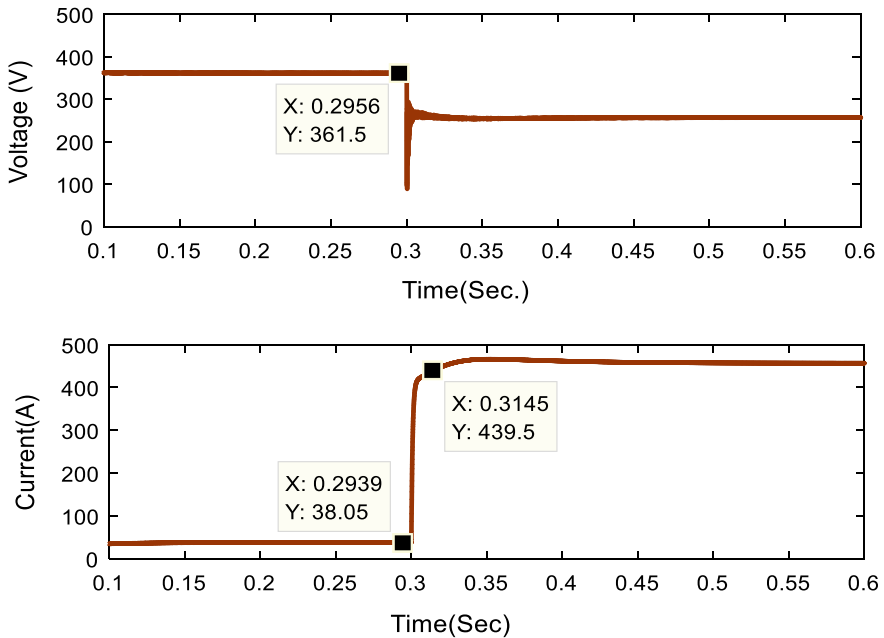


Fig. 2 Voltage and current during a pole to ground fault in section A1

instant of fault inception, an abrupt variation in voltage and current profile can be observed.

3 Overview of Support Vector Machine (SVM)-Based Scheme

Support vector machine is the widely used method of machine learning which is mostly used to perform the classification and regression task. It is based on supervised learning and works on the principle of pattern reorganization for the classification of input data. In SVM, a set of hyperplanes in infinite space is used for the classification of input data. Separation of any class is done on the basis of estimating the largest distance data point to the nearest data point. If the margin between the separation points will be large, then classifier will produce less error, thus improving the accuracy of the system. The equation of hyperplane for the separation of class is given by the following equation

$$T = (a_i, b_i), < i < n \quad (1)$$

where a_i shows the real vector and b_i represent the class of data. Both classes have been represented as

$$w \cdot x - c = 0 \quad (2)$$

where w is the normal vector at the origin point, c is the bias and x is the setting point in a hyperplane. It is desirable that the distance between the planes should be maximum. Equations (3) and (4) show the class of data, i.e., first and second class. These equations also help in ignoring the data lying in the hyperplane. The classification probability is estimated to be good if the margin between the planes will be maximum. The equation for classification is represented as

$$w \cdot x - c \geq +1 \quad (3)$$

$$w \cdot x - c \leq -1 \quad (4)$$

Here $+1$ and -1 represent the values of b_i for the first and second class, respectively.

4 Development of Protection Scheme

In the proposed protection scheme, the sampled signals of voltage and current are utilized for fault detection and classification. In Fig. 3, the outline of the proposed SVM-based protection scheme is illustrated with the help of the flow chart. The post-fault voltage and current signals is recorded at the PCC by simulating the diverse scenarios involving dissimilarity in resistance, location of fault and load variation which is utilized to train the SVM classifier. The task of mode detection is developed by SVM-1 with two output class, i.e., GC and IM representing grid-connected and islanding mode of operation of DC microgrid, respectively. The values of parameters used to train the SVM modules are detailed in Table 1. The detailed description of the development of SVMs dedicated to perform the intended protection tasks of fault detection, classification and section identification is given below.

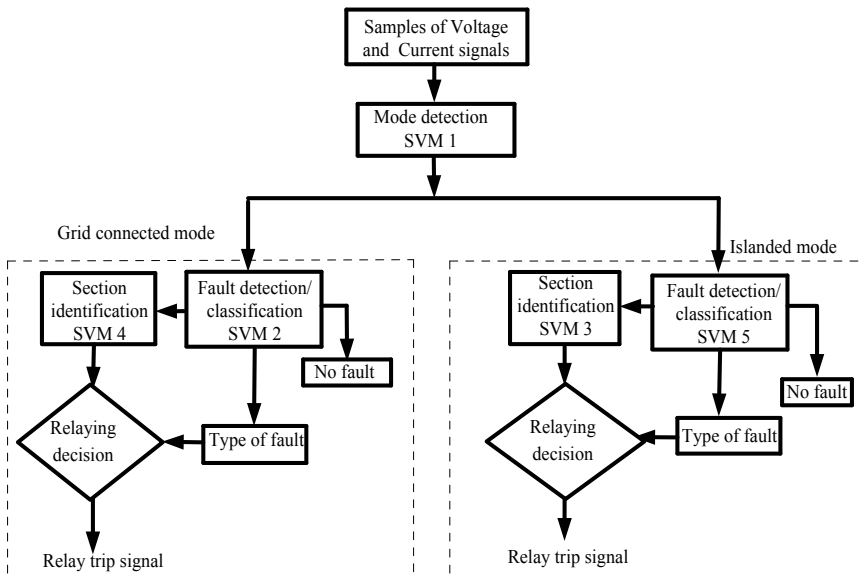


Fig. 3 Flow chart of support vector machine-based algorithm

Table 1 Values of parameters for SVM modules

Parameters	SVM-1	SVM-2	SVM-3	SVM-4	SVM-5
No. of parameters	2	2	2	2	2
Kernel function	Linear	Linear	Linear	Quadratic	Linear
Box constrained level	1	1	1	1	1
Kernel scale	1	3	2	2	3

4.1 Fault Detection/Classification (FD/C)

The task of FD/C is performed by SVM-2 and SVM-5 in grid-connected and islanded mode, respectively. The sampled voltage–current signals constitute the input data to be fed to the SVM. The respective SVM modules provide the output regarding the state of the system (faulty or healthy) and the type of fault among the probable fault types, i.e., pole to ground and pole to pole fault.

4.2 Section Identification

For section identification, the modules SVM-4 and SVM-3 are developed to perform the faulty section identification in both modes, respectively. In the proposed protection model, six sections have been considered.

In case a fault is detected, then depending on the output of section identification module regarding the faulty section, a trip signal is issued by the relay to disconnect the healthy section from the faulty section in the microgrid. A dataset of 726 PG (pole to ground), 66 PP (pole to pole) fault scenarios in each mode has been considered during the training of SVM.

5 Performance Evaluation

The effectiveness of the proposed scheme (FD/C schemes) has been analyzed for different operating conditions involving variation in fault parameters, i.e., faults resistance, location of the fault in each mode of operation. The total number of test scenarios in each mode of operation includes 132 PG, 66 PP and 100 no-fault cases. The description of results for the tested cases is detailed in next subsections.

5.1 Mode Detection

Performance evaluation of proposed SVM-based mode detector has been evaluated and results are depicted in Table 1.

An accuracy of 100% has been achieved by mode detector during the grid-connected mode while in islanded mode, it is 98.66%. The higher level of accuracy in both modes of operation indicates the appropriateness of mode detection module in identifying the appropriate mode of operation.

Table 2 Classification from detection/classification

Type of fault	Types of mode		Overall accuracy (%)
	Grid-connected mode (%)	Islanded mode (%)	
Pole to ground fault	100	92.42	96.21
Pole to pole fault	98.66	91	94.83

Table 3 Testing accuracy (%)

Section	Mode of operation (accuracy in percentage)		Overall accuracy percentage (%)
	Grid-connected mode (%)	Islanded mode (%)	
A1	98.48	97.48	97.98
A2	97.96	96.48	97.22
A3	98.48	96.96	97.92
A4	96.96	95.48	96.22
A5	96.96	98.48	97.72
A6	98.47	95.48	96.97

5.2 Fault Detection/Classification

The performance of SVM-based fault detector/classifier in grid-connected as well as in the islanded mode is summarized in Table 2. As observed, the testing accuracy is higher for both the fault types which reflect the efficiency of the scheme in detecting and classifying the fault scenarios accurately and reliably.

6 Section Identification of Faulty Section

Performance of SVM-based scheme for section identification in grid-connected and islanded mode has been analyzed and the obtained result is summarized in Table 3. As observed, the higher degree of testing accuracy in identifying the faulty section in both the modes of operation of DC microgrid has been achieved with the proposed SVM-based section identifier, which indicates its effectiveness in identifying the faulty section accurately.

7 Conclusion

The integration of DERs in the power distribution network poses a serious protection challenge due to extensive dissimilarity in the voltage–current profile during both modes of operation. In this regard, a SVM-based algorithm is developed for the

protection of the DC ring microgrid system. The proposed scheme involves post-fault sampled signals (voltage and current) utilized by SVM for performing the tasks of fault classification/detection as well as section identification under both modes of operation. The above scheme has been validated for various scenarios involving extensive disparity in fault and no-fault conditions. The performance evaluation indicates the ability of the scheme in providing accurate and reliable protection to the DC microgrid.

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