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Research Paper

# Fault Detection in Ring Based Smart LVDC Microgrid Using Ensemble of Decision Tree

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**Abstract:** In modern infrastructure, the demand for DC power-based appliances is rapidly increasing, and this phenomenon has created a positive impact on the acceptance of the DC microgrid. However, due to numerous issues such as the absence of zero crossing, bidirectional behavior of current, different magnitudes of fault current during grid connected and islanded modes of operation protection of the DC microgrid remains a difficult task. Apart from these challenges, intermittent conditions are also a major challenge throughout the year. Under such type scenarios, shadow conditions in the solar based DERs will reduce the desired output of the solar panels simultaneously wind based DERs will be also affected due to the low pressure of air. In this type of circumstances, threshold setting based overcurrent relays may fail to sense the operational dynamics of the system. Therefore, in this manuscript, an ensemble of decision tree-based protection scheme is proposed to provide immunity against the stochastic conditions under the varying nature of the fault resistances. A total of 7150 test cases have been considered for validation of the protection scheme and all modules have been tested. After successful testing of the modules, the accuracy of the mode detection module is 99.23% for grid connected mode and 98.16% for islanded mode. Similarly, for fault detection/classification modules, accuracies are 99.06% and 97.98% respectively for both of the modes. The outcomes after validation of the protection scheme reveal that the protection scheme is robust and efficiently working.

**Keywords:** DC Microgrid, Ensemble of Decision Tree, PG and PP Fault, Weather Intermittency, Grid Connected and Islanded Mode.

## 1 Introduction

IN this arena, electrical appliances are enormously increasing in domestic and commercial sectors, therefore, demand of the electrical power is tremendously growing. A number of bulk power generating sites, such as coal, nuclear, and other petroleum product-based plants, are installed all over the world to balance the actual demand of power at the consumer end and the availability of generated power.

However, these plants are unable to balance the load demand during peak hours and heavy load conditions. The other major drawback of such plant is the contamination of the air due to hazardous partials such as CO, $CO_2$, $SO_2$, and some other partials. Therefore, the attention of power system engineers is continuously rising towards the adoption of some alternate sources of energy such as PV, wind, tidal, biogas, biomass, and geothermal based plants with the formation of some small and low-scale grids on the consumer end side, which is known as the microgrid [1]. The microgrid is the amalgamation of DERs (distributed energy resources), power electronics converters, loads, and energy storage devices that are constrained by clearly defined electrical boundaries [2-4]. The

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microgrid can be classified into three types (based on the power requirements at the distribution end) such as AC, DC, and hybrid microgrid [5]. Recently, it has been investigated through various research works that the utility of DC based appliances is rapidly growing in the domestic and commercial sectors, such as aircraft [6-7], refrigerators, savers, grinders, mixers, LEDs, data centers, mobiles, batteries [8], shipyard power systems [9], electrical vehicles, household equipment as well as in control center based applications, and this phenomenon has motivated us to form the DC microgrid. The DC microgrid offers many advantages over the conventional AC systems, some of which are the lack of synchronization [10] due to absence of frequency, free from corona effect, no skin effect, fewer power conversion stages, cost effectiveness [11] and higher power transfer capability due to absence of frequency. However, the protection of the DC microgrid is a major issue due to the numerous types of protection challenges, which include the absence of the zero crossing signal [12], distinct magnitude of the fault current during grid connected and islanded mode, pole to ground-(PG) due to grounding of the conductor and pole to pole (PP) fault (these are the types of fault) [13], false tripping, and bidirectional behavior of the converters. Apart from these challenges, the other major consideration is the sporadic or intermittent behavior of the renewable DERs due to the uncertain weather conditions throughout the years. In these conditions, the threshold value based overcurrent relays may fail to sense the behavior of the system if a fault occurs and they may maloperate, if the magnitude of the fault current is equal to the normal condition. As a result, the DER existing in the power distribution network can be disconnected from the system. To highlight the problem concerned with weather intermittency and its effect on the possible detection of fault, a set of simulations have been illustrated in Fig. 1 and Fig. 2. In both of the figures, it can be investigated that under wind intermittency and low resistance fault, the magnitude of the fault current is greater as compared to Fig. 2, where the magnitude of the fault current is less under the high value of the fault resistance. Therefore, the detection of the fault is critical when fault current is approximately equal. A number of protection schemes have been reported by the researchers regarding the protection of DC microgrids, some of which are the signal handshaking methods for locating and isolating faults [13], centralize unit base protection scheme [14], a cumulative sum-based fault detector in [15], protection of smart DC microgrid with ring configuration [16], travelling wave-based methodology [17], adaptive threshold [18], wavelet transform based protection scheme for LV DC microgrid [19], superimposed current based unit protection scheme [20], a Pearson correlation coefficient based protection scheme for mesh type DC microgrid [21] and Bifurcation theory assisted overcurrent scheme [22]. However, proposed schemes are unable to predict the sporadic conditions due to weather intermittency and their impact on the voltage and current profiles.

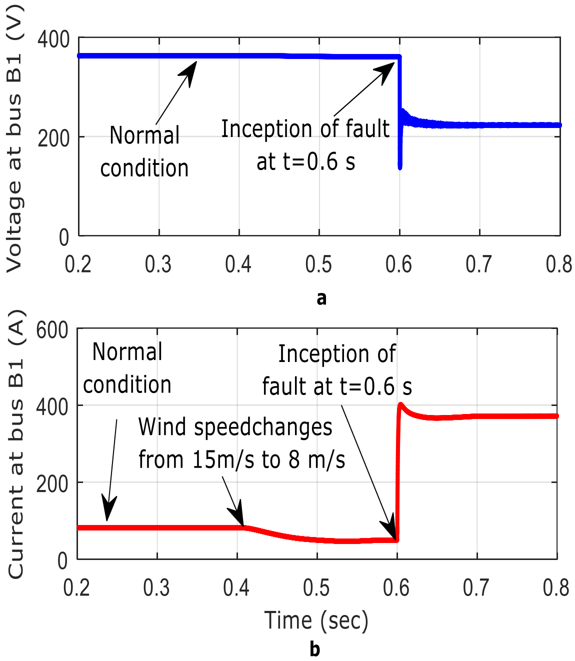

**Fig. 1** Impact of the wind intermittency and low fault resistance on the PG fault

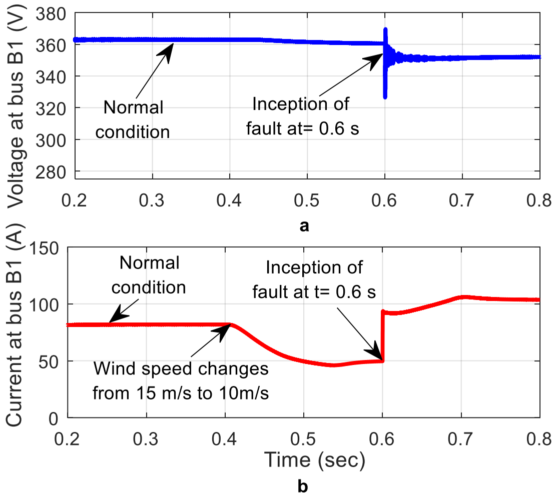

**Fig. 2** Impact of the wind intermittency and high fault resistance on the PG fault

To explore the advantages and disadvantages of the fault detection schemes that have been proposed by the authors is dealt in Table 1.

**Table 1** Fault detection algorithms for DC microgrid

| S.N. | Name of fault detection methods | Advantages | Disadvantages |
|---|---|---|---|
| 1 | Signal handshaking based scheme | No need of communication system, simple and reliable, low cost. | Complete system shutdown after identification of fault as well as reduced reliability of the system. |
| 2 | Centralize unit base protection scheme | Protection scheme provides back up protection and capable of restoring the power distribution network. | The main drawback of this type of protection scheme is its requirement of a signal generator, as well as threshold selection, which is also a critical issue. |
| 3 | A cumulative sum-based fault detection scheme | Protection scheme is efficient and reliable for detection of sudden variations. | Cost as well as failure of communication link is a major issue. |
| 4 | Travelling wave-based method | Fast operation , high sensitivity and selectivity. | Implementation of the scheme is difficult and requires a higher sampling frequency for operation, Requirement of smoothing reactors in terminals of the line. |
| 5 | Wavelet transform based method | Detection of high resistance faults, determination of varying frequency during transient conditions with respect to time, and fast. | Threshold selection for large power distribution network is difficult. Maloperation during temporary faults. |
| 6 | Superimposed current based unit protection scheme | Proficient method for the identification of internal and external faults. | Synchronization of signal and relay maloperation during healthy condition is the main disadvantage of the method. |
| 7 | Person correlation coefficient based method | Robust method for detection of the fault and identification of fault type. | The threshold selection for a vast network is complicated. |
| 8 | Bifurcation Theory assisted overcurrent scheme | Efficient for detection of the HRF and bolted fault, detection of weak signals, No need of threshold selection. | Need of intelligent electronic devises and other electronic accessories, probability of failure in communication system may affect the reliability of the system. |

On the basis of the observation from below table, it is analyzed that major of them are working on the principle of the threshold setting of relays and the schemes are insensible under uncertain operation of the DERs. In this context, an ensemble of decision tree-based protection schemes is proposed to improve the invulnerability and robustness by improving the system resiliency under the grid connected and islanded mode of operation. In recent years, the ensemble-based algorithm has been widely used in research for data classification, such as high impedance fault detection [23], landslide susceptibility mapping [24], and plant failure detection [25]. The major contribution of this work can be summarized as follows:

i. Modeling of the wind intermittency to observe the behavior the intermittency through Weibull function.
ii. Development of the ensemble of protection schemes to identify the mode of operation, fault detection/classification with faulty section identification.
iii. Validation of the proposed scheme through the test cases under diverse conditions.
iv. Simulation of the DC microgrid model to simulate the fault scenarios.
v. Analysis of the protection scheme with other techniques.

The rest of the article is organized as follows: section 2 describes the configuration of the DC microgrid, while section 3 deals with the modelling of the wind intermittency. In sections 3 and 4, the overview of the proposed ensemble and the development of the protection scheme are illustrated in detail. Further, performance analysis is carried-out in section 5, followed by conclusion in section 6.

## 2 Configuration of the DC Ring Test Microgrid Model

In this section, the single line diagram of the LVDC microgrid is given which is illustrated in Fig. 3 [16]. In proposed figure the PV array, synchronous diesel generator, and wind-based DERs are integrated in the different places through buses B2, B4, and B6 respectively. Two loads, namely L1 and L2, have also been amalgamated into buses B2 and B4. The entire length of the proposed LVDC microgrid network is six kilometer, where each section is extended over the length of one kilometer. To simulate the test microgrid model, MATLAB/SIMULINK software is used. As depicted in the proposed figure that the output of each unit delivering and consuming power is not homogeneous. Therefore, power converters are integrated with each bus to ensure desired output. To observe the fault scenarios in the proposed DC microgrid system, six faults from F1 to F6 have also been considered. Sampling frequency of the system is 4 kHz. To integrate the utility grid with the rest of the DC microgrid, AC to DC bidirectional is used with a switch. Therefore, the DC microgrid can be operated in a grid connected as well as an islanded mode of operation.

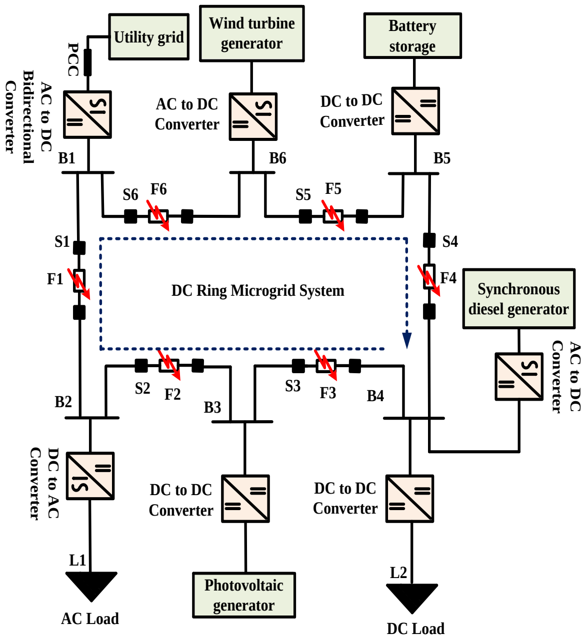

**Fig. 3** Single line view of the DC microgrid

## 3 Modelling of Wind Intermittency

Modelling of the wind intermittency is proposed to examine the variations in the wind speed throughout in this section. Therefore, to observe the uncertain behavior of the wind speed, the Weibull distribution function (Eq. (1)) is considered in Fig. 4 as well as a plot of the density observation function in Fig. 5 using the metrological data of NREL [26]. The effectiveness of the proposed function is dealt in [27].

$$f(v) = \frac{b}{a}\left(\frac{v}{a}\right)^{b-1} \exp\left(-\left(\frac{v}{a}\right)^{b}\right) \qquad (1)$$

Here *a* and *b* are the scale and shape of the Weibull distribution function respectively.

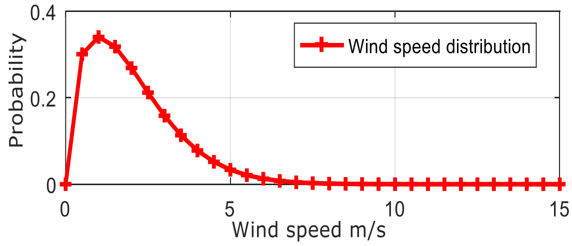

**Fig. 4** Probability distribution function (Weibull function).

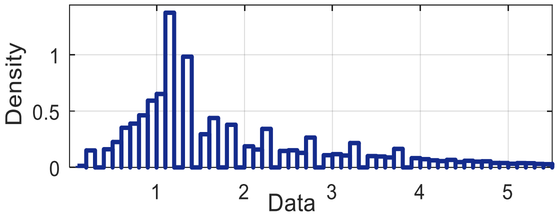

**Fig. 5** Density observation plot under varying wind speed.

## 4 Overview of the Ensemble of Decision Tree

In modern research technology, ensemble-based classifiers have become a popular data mining tool among many of the available machine learning techniques. The accuracy of the ensemble-based classifiers is greater as compared to the standalone units of the classifiers. Therefore, ensemble based classifiers are widely accepted for the classification of datasets. To elaborate on the view of the ensemble of the decision tree in Fig. 6 is used, where it can be observed that initially the datasets are utilized by the different units of the decision tree from DT-1 to DT-N, then the final result is predicted on the basis of the voting strategy for the assigned class of the given datasets.

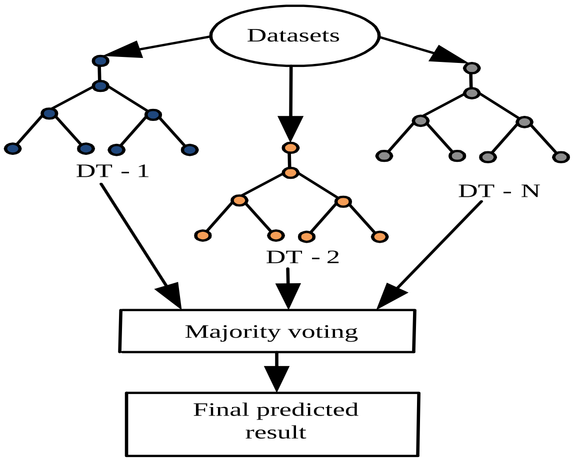

**Fig. 6** Architecture of the ensemble based decision tree.

## 5 Development of Protection Scheme

In order to describe the protection scheme, Fig. 7 is considered where a total of five units of the ensemble of decision trees are considered. Firstly, the samples of the voltage and considered are retrieved from the bus B1 and then utilized to train each module of the protection scheme. Here, ENSDT-1 is considered for the mode detection while others are considered for the fault detection/classification as well as the section identification in the grid connected and islanded mode of the operation.

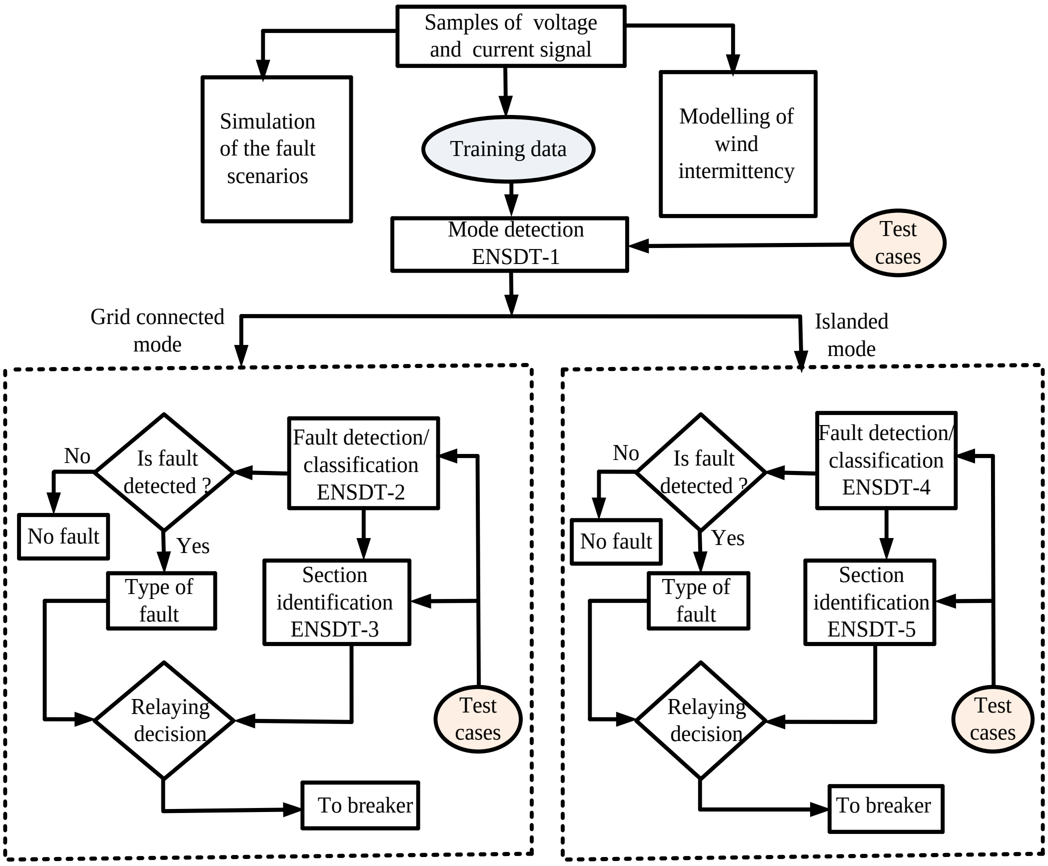

**Fig. 7** Ensemble of decision tree protection scheme.

In proposed protection scheme ENSDT-2 and ENSDT-3 are utilized for fault detection/classification, and section identification during grid connected mode, while ENSDT-4 and ENSDT-5 are considered for the islanded mode of operation. If the fault is detected and the faulty section is identified, then the relay will issue the trip signal to operate the circuit breaker, otherwise, a healthy condition will be detected by the protection scheme.

## 6 Performance Analysis

In this section, the robustness of the protection scheme is proposed to analyses the invulnerability of the protection scheme. A total number of 23832 cases have been generated through the simulation of the proposed DC microgrid system, which is depicted in Table 2. To generate the proposed datasets, a number of diverse conditions have been considered, such as variation in fault resistance, length of fault, and variation in wind speed. Further, proposed generated datasets are utilized for training and testing of the different modules of the proposed protection scheme (as depicted in Fig. 7). In this section, analysis of the mode identification, fault detection/classification as well as section identification are reported under grid connected as well as the islanded mode of operation. To clearly illustrate the analysis of the above tasks, six subsections are considered.

### 6.1 Mode Identification Using ENSDT-1

Mode detection plays a vital role in the protection scheme to automatically trigger the algorithm in the next stage.

**Table 2** Training and testing pattern and data generation

| Parameters during training of classifiers | Specification of fault parameters during training and testing | Total cases | Total training cases | Total testing cases |
|---|---|---|---|---|
| Types of mode | 2 | Total cases<br>=23232<br>+600=23832 | 16682 | 7150 |
| Section | 6 | | | |
| Types of fault | 2 | | | |
| Fault resistance | 11 | | | |
| Length of fault | 11 | | | |
| Inception of fault | 1 | | | |
| Wind speed variation | 8 | | | |

**Table 3** Comparison of the percentage accuracies for proposed mode detector (ENSDT-1)

| Types of algorithms | Mode of operation | | Accuracy (%) |
|---|---|---|---|
| | Grid connected (%) | Islanded mode (%) | |
| ENSDT | 99.23 | 98.16 | 98.69 |
| DT | 97.85 | 96.66 | 97.25 |
| ANN | 95.94 | 94.69 | 95.31 |

**Table 4** Comparison of the proposed fault detector/classifier in terms of the reliability indices

| Type of algorithms | Types of mode | | | | | |
|---|---|---|---|---|---|---|
| | Grid connected | | | Islanded | | |
| | Dependability (%) | Security (%) | Accuracy (%) | Dependability (%) | Security (%) | Accuracy (%) |
| ENSDT | 98.97 | 99.16 | 99.06 | 97.86 | 98.11 | 97.98 |
| DT | 97.58 | 97.44 | 97.51 | 95.23 | 96.98 | 96.10 |
| ANN | 96.37 | 96.92 | 96.64 | 95.66 | 94.81 | 95.23 |

Therefore, in this subsection, the task of mode identification is examined, with a total of 2170 test cases that have been used to test the module ENSDT-1 in both grid-connected and islanded mode of operation. After successful testing of mode detection module, results are dealt in Table 3. To clearly observe the robustness of the mode identifier, two other mode detectors, which are DT and ANN, have also been considered on the same number of testing datasets. The observations in Table 3 indicate that the proposed ensemble-based mode detector is more accurate and reliable in terms of percentage accuracy. To clearly depict the accuracy of the mode detector, a bar graph has also been plotted in Fig. 8, where the differences in the percentage accuracies can be examined.

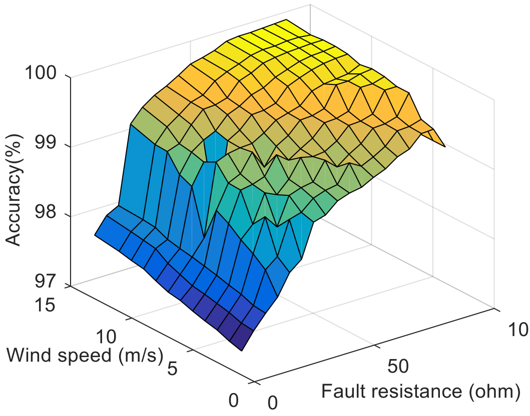

**Fig. 8** Performance of the protection scheme during variation in wind speed and fault resistances (grid connected mode)

### 6.2 Fault Detection/Classification and Analysis Using Reliability Indices (ENSDT-2 and ENSDT -4)

Prompt identification of the faulty conditions is essential in the existing power distribution network to improve the system resiliency and restoration the power system. Therefore, in this subsection, performances of the fault detection modules are analyzed under both modes of operation. A total of 1776 fault cases have been considered to test the modules ENSDT-2 and ENSDT-4. Further, the efficacy of the protection scheme has been analyzed through the two reliability indices, which are dependability and security. Here, dependability is helpful in the determination of the possible detection and misdetection of faults, while security can indicate the possible generation of a false alarm signal. For the mathematical calculation of both of the indices, Eq. (2) and Eq. (3) have been used, where the ratio of the predicted fault and no fault cases has been utilized for calculation. The detection rate will be higher if the percentage accuracy of these indices is greater. Table 4 shows the percentage accuracies of the proposed ensemble base fault detector/classifier for both of the modes. The test Results in the table 4 revels that the proposed protection scheme outperforms when compared to the DT and ANN-based techniques on the same datasets.

$$\text{Dependability} = \frac{\text{Actual predicted fault cases}}{\text{Total nmber of fault cases}} \quad (2)$$

$$\text{Security} = \frac{\text{Actual no fault predicted cases}}{\text{Total number of no fault cases}} \quad (3)$$

### 6.3 Section Identification (ENSDT-3 and ENSDT-5)

Performance of the any type of power distribution network can be improved, if the protection scheme is capable for rapid isolation of the faulty section. Therefore, performance of the proposed ENST based section identifier modules have been analyzed under the grid-connected as well as islanded mode of operation in this subsection. A total of 3204 test cases have been utilized to test the section identifier modules (S1 to S6). After successful testing the results are analyzed in Table 5 and Table 6. The results in the below table demonstrate that the proposed section identifier is robust and able to perform the section identification task under the grid connected as well as in the islanded mode of operation.

### 6.4 Response of the Proposed Protection Scheme under Variation of the Wind Speed and Fault

As described in section 1 that intermittent conditions can affect the profile of the system. Therefore, in this subsection, the response of the protection scheme is given for the observation of its accuracy against the intermittency and fault. It has been observed from Table 7 and Table 8 that the proposed scheme is able to detect the fault under intermittent conditions and also relay execution time is less. To illustrate the performance of the fault classifier during both of the modes Fig. 8 and Fig. 9 has been plotted where rise and falls in the both of the figures shows the variation in the classification accuracy during PG and PP faults. Fault resistance, variation in wind speed as well as percentage accuracy during the classification is considered to plot the both of the figures. Wind speed is varied between 5 and 15 m/s, while fault resistance is varied between 10 Ω and 100Ω for both 3-D plots. After post fault condition generation of the trip signal for both types of faults are clearly demonstrated, whose responses are depicted in Fig. 10 and Fig. 11 (for grid connected mode and PG faults) as well as Fig. 12 and Fig. 13 for islanded mode and PP faults.

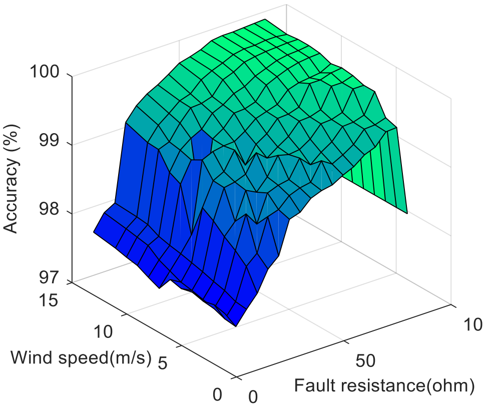

**Fig. 9** Performance of the protection scheme during variation in wind speed and fault resistances (islanded mode).

**Table 5** Performance of the section identifier under grid connected and islanded mode (PG fault).

| Mode of operation | Section | No of actual given test cases | Actual predicted test cases | ENSDT (accuracy %) |
|---|---|---|---|---|
| Grid connected mode | S1 | 296 | 292 | 98.64 |
| | S2 | 206 | 204 | 99.02 |
| | S3 | 240 | 238 | 99.16 |
| | S4 | 260 | 258 | 99.23 |
| | S5 | 284 | 282 | 99.29 |
| | S6 | 316 | 312 | 98.73 |
| | | Overall accuracy (%) | | 99.01 |
| Islanded mode | S1 | 210 | 204 | 97.14 |
| | S2 | 216 | 209 | 96.75 |
| | S3 | 290 | 279 | 96.20 |
| | S4 | 386 | 378 | 97.92 |
| | S5 | 240 | 235 | 97.91 |
| | S6 | 260 | 251 | 96.53 |
| | | Overall accuracy (%) | | 97.07 |

**Table 6** Performance of the section identifier under grid connected and islanded mode (PP fault).

| Mode of operation | Section | No of actual given test cases | Actual predicted test cases | ENSDT (accuracy %) |
|---|---|---|---|---|
| Grid connected mode | S1 | 52 | 51 | 98.07 |
| | S2 | 58 | 58 | 100 |
| | S3 | 50 | 50 | 100 |
| | S4 | 60 | 59 | 99.33 |
| | S5 | 45 | 45 | 97.77 |
| | S6 | 63 | 63 | 100 |
| | | Overall accuracy (%) | | 99.30 |
| Islanded mode | S1 | 60 | 58 | 96.66 |
| | S2 | 50 | 50 | 100 |
| | S3 | 52 | 50 | 97.15 |
| | S4 | 58 | 56 | 96.55 |
| | S5 | 53 | 52 | 98.11 |
| | S6 | 55 | 55 | 96.36 |
| | | Overall accuracy (%) | | 97.47 |

**Table 7** Response of the protection scheme under variations in the fault resistance and wind speed for PG fault.

| Types of mode | Type of fault | Fault resistance | Variation in the wind speed (m/s) | Faulty section | Response of DT | Relay trip time (ms) |
|---|---|---|---|---|---|---|
| Grid connected | PG | 50 | 6 | S1 | PG | 1.6 |
| | PG | 75 | 8 | S3 | PG | 1.9 |
| | PG | 80 | 12 | S4 | PG | 1.5 |
| | PG | 85 | 15 | S5 | PG | 1.6 |
| | PG | 100 | 14 | S6 | PG | 1.9 |
| Islanded mode | PG | 50 | 10 | S6 | PG | 1.8 |
| | PG | 75 | 9 | S2 | PG | 2.1 |
| | PG | 80 | 11 | S5 | PG | 1.7 |
| | PG | 85 | 8 | S1 | PG | 2.2 |
| | PG | 100 | 15 | S3 | PG | 1.8 |

**Table 8** Response of the protection scheme under variations in the fault resistance and wind speed for PP fault.

| Types of mode | Type of fault | Fault resistance | Variation in the wind speed (m/s) | Faulty section | Response of DT | Relay trip time (ms) |
|---|---|---|---|---|---|---|
| Grid connected | PP | 0.4 | 10 | S2 | PP | 1.5 |
| | PP | 0.4 | 8 | S5 | PP | 1.6 |
| | PP | 0.4 | 15 | S6 | PP | 1.3 |
| | PP | 0.4 | 12 | S4 | PP | 1.5 |
| | PP | 0.4 | 14 | S1 | PP | 1.7 |
| Islanded mode | PP | 0.4 | 13 | S1 | PP | 1.7 |
| | PP | 0.4 | 11 | S3 | PP | 1.9 |
| | PP | 0.4 | 10 | S4 | PP | 1.5 |
| | PP | 0.4 | 15 | S5 | PP | 1.7 |
| | PP | 0.4 | 4 | S6 | PP | 1.6 |

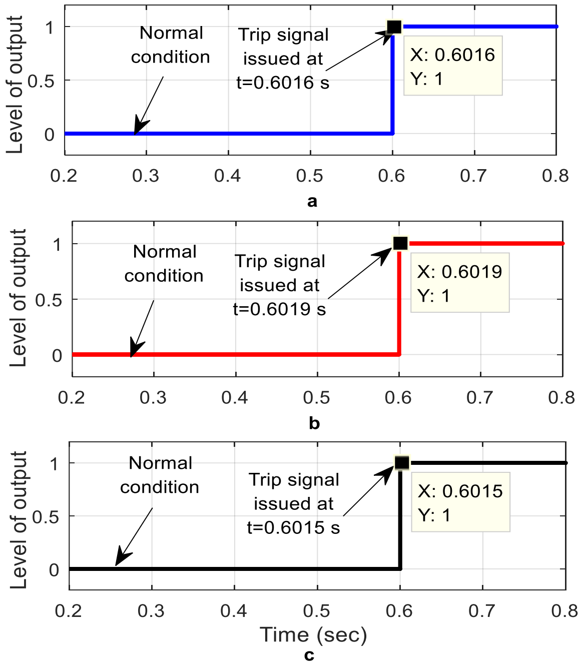

**Fig. 10** Response of proposed scheme under grid connected mode and PG faults.

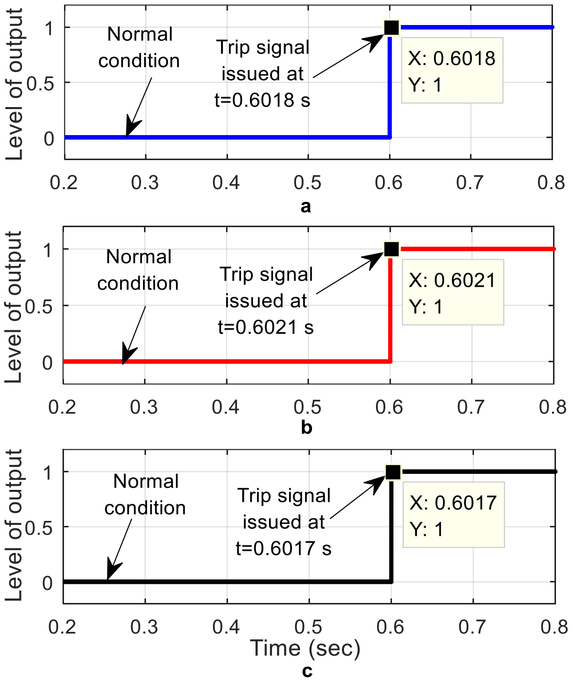

**Fig. 11** Response of proposed scheme under islanded mode and PG faults.

After examining the entire trip signal plots, it has been observed that the relay execution time for both types of fault scenarios is very less. As illustrated in Fig. 3 that, PV based DER is also integrated in the test model of DC-microgrid, therefore the same analysis can be also performed for the variation in the solar irradiance with respect to the varying weather conditions.

## 6.5 Performance of Protection Scheme under Uncertain Load Conditions

In this subsection, response of the protection scheme under uncertain loading conditions have been evaluated and demonstrated in Table 9. The range of the uncertain load conditions is considered between ±20 to±60 percent. Linear as well as nonlinear load has been considered for uncertain load variation under both of the modes respectively. Grid connected as well as islanded modes have been used for analysis of the uncertain load variations. Linear load has been varied in grid connected mode while nonlinear load during islanded mode of operation. After investigation from the below table it is analyzed that protection scheme is accurate even in uncertain loading conditions also.

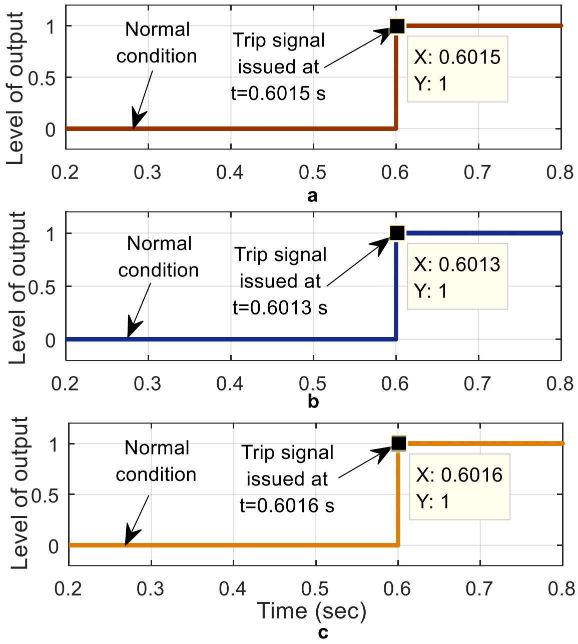

**Fig. 12** Response of proposed scheme under grid connected mode and PP faults.

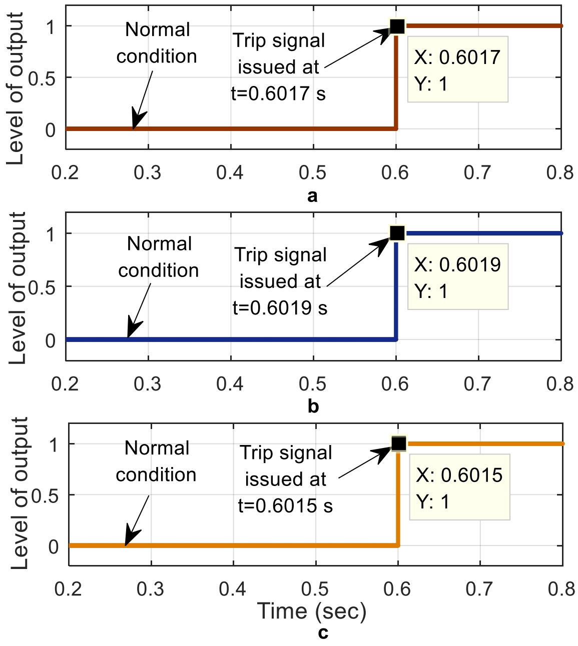

**Fig. 13** Response of proposed scheme under islanded mode and PP faults.

**Table 9** Response of the scheme during uncertain load variations.

| Types of mode | Load variation | Type of fault | Response of protection scheme |
|---|---|---|---|
| Grid connected | ±20 | PG | PG |
| | ±40 | PG | PG |
| | ±60 | PG | PG |
| | ±20 | PP | PP |
| | ±40 | PP | PP |
| | ±60 | PP | PP |
| Islanded mode | ±20 | PG | PG |
| | ±40 | PG | PG |
| | ±60 | PG | PG |
| | ±20 | PP | PP |
| | ±40 | PP | PP |
| | ±60 | PP | PP |

### 6.6 Comparison of the Proposed Protection Scheme with Other Reported Techniques

In this subsection, a comparison of the proposed scheme is given with the reported literature on the basis of some parameters. From Table 10, it is clear that the proposed scheme is able to perform the assigned task and outperforms as compared to reported schemes.

## 7. Conclusion

The growth of DC based appliances is rapidly rising in modern life. Therefore, the necessity of the DC-based microgrid is tremendously increasing. However, the acceptance of the DC microgrid is limited due to many difficulties. In this manuscript, an ensemble of decision tree-based protection schemes is proposed under the wind intermittency and varying nature of fault resistances. A total of 7150 cases have been considered to test the different modules of the proposed protection scheme. To design, the datasets for the training and testing purposes of the modules signals were retrieved from the bus B1, which is near to the utility grid. After investigation in section 5, it is concluded that the ensemble of decision tree-based protection schemes is capable of performing the assigned task under the sporadic nature of DERs.

## Intellectual Property

The author confirms that they have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing to publication, with respect to intellectual property.

## Funding

No funding was received for this work.

**Table 10** Comparison of the proposed scheme with reported literatures.

| Parameters of comparison | Microgrid protection schemes | | | |
|---|---|---|---|---|
| | [15] | [16] | [19] | Proposed scheme |
| Input features | Current | Current | Current | Voltage and current |
| Fault parameters | Resistance, location of fault | Not considered | Resistance, location of fault | Resistance, length of fault, location of fault |
| Tasks performed | Fault detection and location | Fault detection | Fault detection and location estimation | Mode detection, fault detection, classification and section identification |
| Test cases | NC | NC | NC | 7150 |

## CRediT Authorship Contribution Statement

**S. P. Tiwari:** Data curation, Conceptualization, Methodology, Software, Formal analysis, Original draft writing, Review and editing.

## Declaration of Competing Interest

The author hereby confirms that the submitted manuscript is an original work and has not been published so far, is not under consideration for publication by any other journal and will not be submitted to any other journal until the decision will be made by this journal. The author has approved the manuscript and agree with its submission to “Iranian Journal of Electrical and Electronic Engineering”.

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## Biography

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