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Transient wavelet energy-based protection in microgrid power system

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ABSTRACT

This paper is discussed a transient current-based microgrid connected power system protection scheme using the Wavelet Approach described on wavelet detailed coefficients of Mother Biorthogonal 1.5 wavelet. The proposed algorithm is tested in a microgrid connected power systems environment and proved for the detection, discrimination, and location of faults which is almost independent of fault impedance, fault inception angle (FIA), and fault distance of feeder line.

1. Introduction

The increase in demand for energy worldwide requires the use of various electric power sources combined with a common grid for making an efficient electrical energy system. The DERs are becoming more popular compared with conventional integrating systems. In many cases, DERs generate power with different technologies through micro sources like Solar Photovoltaic and wind energy during the decade. The concept of microgrids has emerged as an incredible way to integrate micro sources into the electric power network. Its benefits mainly, it supplies local power, reducing grid costs due to few Megawatts, reducing operation costs, system losses, and peak time load problems such that increasing reliability (Ding et al., 2009). Micrograds have considerable advantages on the issue of their protection. In a conventional network, power flows from the HV level to the LV level, and during the fault the shortcircuit current decrease as distance increases. The concept of the modern microgrid has been changed and power flow is bidirectional. Some of the main important protection (Oudalova and Fidigattibfd, 2011) issues are: shortcircuit power, the current level of fault and its direction, device discrimination, uneven tripping, protection blinding, etc. There are some main issues like the determination of the time at the time of islanding from the main grid in response to abnormalities. Conventional methods of detection and discrimination of faults are becoming unreliable due to the increasing size of the network and inefficient algorithms. The setting of threshold levels based on current or voltage amplitudes is frequently prone to mistakes such that a tripping decision maybe becomes a wrong judgment for small disturbances in the system and sometimes gives the maloperation of tripping without any fault in the system. The necessity of well-coordinated and reliable protection scheme is needed so that it can be tripped reliably during the occurrence of a fault within it. The research proposed here is done for the detection, discrimination, and location of faults on DERs integration in transmission networks using Wavelet-based Multi-resolution Analysis using Wavelet transform. For this purpose, the 3-Φ current signals of the local terminal are decomposed with Mother Biorthogonal 1.5 wavelet, over a ½ cycle window and analyzed the hidden information of the fault situation in the network. The detection and discrimination of fault can be done within a ½ cycle using detail coefficients of current signals. A new algorithm is described which is independent of fault impedance fault location and FIA. The proposed protection scheme is proven to be fast, accurate, and reliable for various types of faults on Microgrid Connected Power systems.

2. Technical challenges in microgrid protection

The microgrid has several challenges mainly protection, controlling, and dispatching perspectives (Wang et al., 2011). But due to their specific mode of characteristics and operation, this protection scheme has to deal with new technical challenges (Ustun et al., 2011). The major challenges are protection schemes for microgrids must respond to main grid and microgrid faults. In case one, the protection scheme has to separate the microgrid from main grid rapidly to protect microgrid loads. In case two, the

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protection scheme has to separate the least priority part of the microgrid rapidly to clear the fault in the system. Some issues related to the protection of microgrids and distributed grids with a large interconnection of DERs have been discussed in recent publications. They are related to the number of installed units in the microgrid and the availability of a sufficient level of shortcircuit current in the islanding mode of a microgrid. The shortcircuit current calculations of radial feeders with DERs observed that shortcircuit currents that are used in overcurrent protection relays depend on a connection point and a feed-in power from DERs. To get high performance and better AC power quality of the converters, it is worthful to control directly the phase angle and magnitude of 3-Φ supply currents (Chaitanya et al., 2017). In addition, controllable islanding of different sizes and content can be formed due to faults in the main grid or within the microgrid.

In such cases, relay loss of coordination may occur and standard overcurrent protection with one trip setting group may become unsatisfactory, therefore, it is essential to ensure that the trip setting to be chosen for overcurrent protection relays taken into account concerning grid topology, change in location, quantity, and type of power generation. Otherwise, maloperation or failure of operation may occur when it is required. This paper is discussed a novel adaptive microgrid protection scheme (Nikkhajoei and Lasseter, 2007; Oudalov et al., 2009) concept by using an advanced type of communication system, real-time measurements, and data collection from offline shortcircuit analysis (Oshaba and Ali, 2014). This concept is based on an adaptation of protective relay trip settings about a microgrid topology, generation, and variation in loads. A segmentation of the microgrid must be supported by micro-sources and load controllers. In these circumstances, problems related to selectivity and sensitivity of protection schemes may arise.

3. Wavelet analysis

Wavelet Transform is a linear transformation like a Fourier-Transform, with only one important difference: for a given signal it permits time localization of different frequency components. So, it is a mathematical analysis used in signal analysis. Wavelet analysis is particularly effective where the signals to be analyzed have discontinuities or transients, e.g., voltage or current signals after the fault. In wavelet transform, the analyzing functions are called Wavelets. The wavelets adjust their time width to their frequency in which, high-frequency wavelets are narrow and low-frequency ones are wider. Wavelet transform is a tool that cuts the data/functions/operators into different components of frequency, and then analyses resolution matched with each component to its scale (Littler and Morrow, 1999).

Wavelets decompose signals of transients in the form of a series of wavelet components each of time-domain signals that cover a specific octave frequency band having detailed information. These wavelet components are useful for detecting and discriminating the sources of surges. Hence, it is feasible and practically proved for analyzing signals of disturbances and transients (Sudhir, 2013).

Wavelet transform plays great importance in the power sector for a decade because it is well suited for the analysis of transient signals than other transform approaches. Power transmission network protection is done with a set of basic functions called Wavelets used to decompose the signal in various frequencies, which are obtained from a Mother Biorthogonal 1.5 wavelet by dilation and translation. So that incidence and amplitude of each frequency can be found accurately (Mallat, 1989). A given function f(t), its continuous wavelet transform be calculated as follows:

$$WT(a,b) = \frac{1}{\sqrt{a}} \; x(t) g \frac{t-b}{a} dt.$$

Where 'a' is scaling (dilation) & 'b' is translation (time-shift) constants and 'g' is the function of wavelet for simplicity which may not be real as assumed in the equation (Makming et al., 2002). The selection of mother-wavelet is based on the type of signal. In the following section, a novel method of Wavelet-based Multi-resolution Analysis of transient currents associated with the fault is discussed for the detection and discrimination of faults (Escudero et al., 2017).

4. System modelling and result analysis

Solar Photovoltaic and wind energy have emerged as energy sources interconnected to a point of common coupling to the main grid intending to generate power that will improve reliability in power supply against the load demand. Both Solar Photovoltaic and wind energy are variable and depend on climatic changes. Fortunately, the problems can be moderately overcome by integrating the DERs to form a hybrid Microgrid system, power generation of one source overcome the limitation of the other power generation (Priyadharshini et al., 2015). The DERs connected to Microgrid are allocated to compensate for the shortage of power as per load demands. However, the interfacing of Microgrid with these DERs makes the number of power quality and islanding issues that must be detected, analyzed, and mitigated effectively. A solar photovoltaic system has an array of cells consisting of PV material in which solar radiation converts to DC and further DC is converted into the alternating current via inverter then it is connected to the utility grid. Maximum power obtained from a Solar Photovoltaic system is directly proportional to solar irradiance intensity. The wind turbine operates like a prime mover coupled to a DC generator. A Pulse Width Modulation (PWM) technique converts the output of the DC generator to 3-Φ AC voltage. Whenever rotor blades strike the wind, the wind turbine extracts maximum K.E from the wind. PWM is used to obtain 3-Φ AC voltage from the output of the DC generator. A 60km length transmission network is considered between Bus1 and Bus2 as a test case in this paper. At 10km distance of transmission network at bus3 formulated with a wind energy source of capacity 9MVA, 575V through a transformer of 575V/25KV is connected. A bus4 formulated with battery, Solar Photovoltaic, and Fuel cell energy source of capacity 400KVA connected through transformer of 575V/25KV. Using the power system block set (PSB) and the SIMULINK software, the test system is simulated. The test system single line diagram is shown in Fig. 1 and the model simulation diagram is described in Fig. 2. The complete algorithm of the proposed scheme is provided below:

Step 1: Determination of the phase currents
Step 2: Calculation of detailed coefficients and sum of detailed-coefficients
Step 3: Comparison of the sum of detailed coefficients with the threshold value
Step 4: Identification of fault on the terminals
Step 5: Classification of the fault type at the terminal by comparing with a threshold value

The 3-Φ currents of the local terminal are analyzed with Mother Biorthogonal 1.5 wavelet to obtain the detailed coefficients over a ½ cycle length moving window. The detailed coefficients are calculated from Bus1, Bus 2, Bus3, and Bus4 to obtain effective D1 coefficients. Each phase's Fault Index is then calculated.

The results plotted for different faults are given below. The location of the fault in the system can be observed by comparing the variation of the measured current index at all buses. Fig. 3 shows the Double line to ground (LLG) fault at terminal1. Phase A to ground fault (LG) at terminal1with an FIA 0^0 which is illustrated in Fig. 4. The Sum of detailed coefficients of phase currents is shown in Fig. 5 and observed that LG fault. All the faulty phase index values are above threshold values can be identified as a type of the fault showing that the LG fault at FIA20^0 as shown in Fig. 6, the LLG fault at FIA40^0 as illustrated in Fig. 7, the LL fault at FIA20^0 as shown in Fig. 8 and 3-Φ fault at FIA20^0 as shown in Fig. 9 Figs. 6-9 shows the fault index variation for transmission system LG, LL, and LLG fault at FIA 40^0 from terminal1.

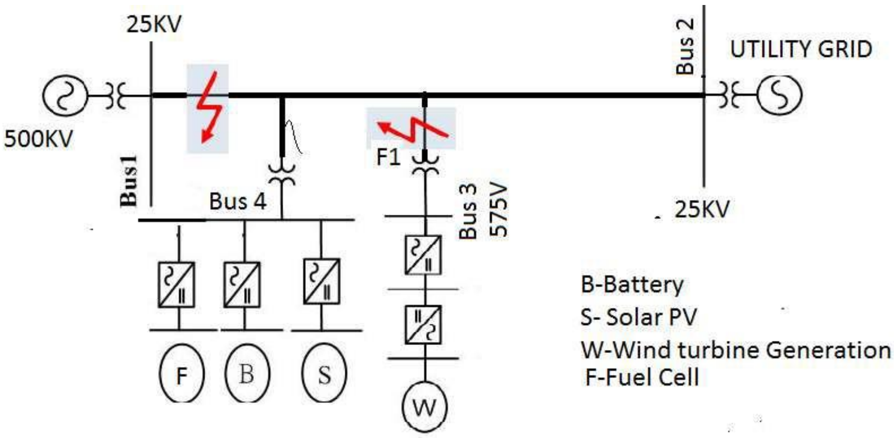

Fig. 1: Single line diagram for microgrid connected to the utility grid

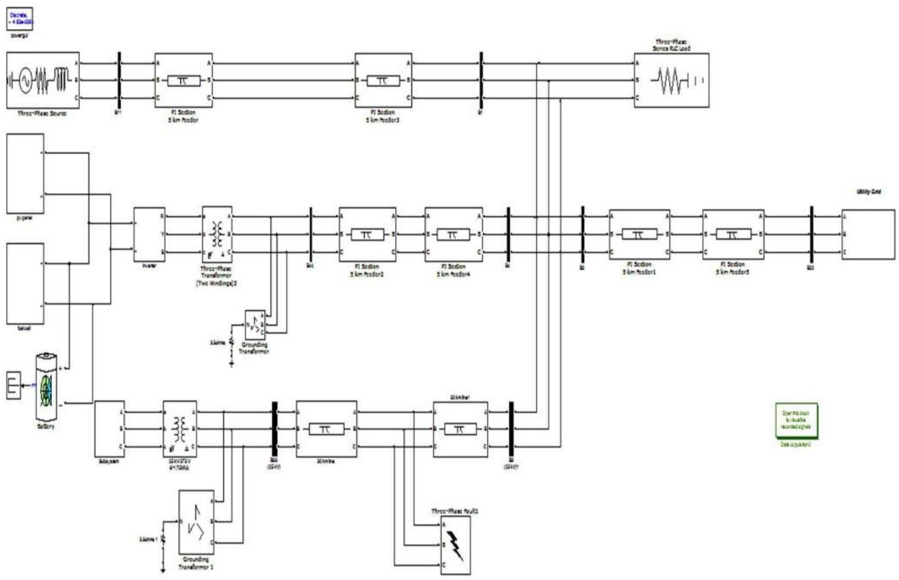

Fig. 2: Simulation model for the proposed system

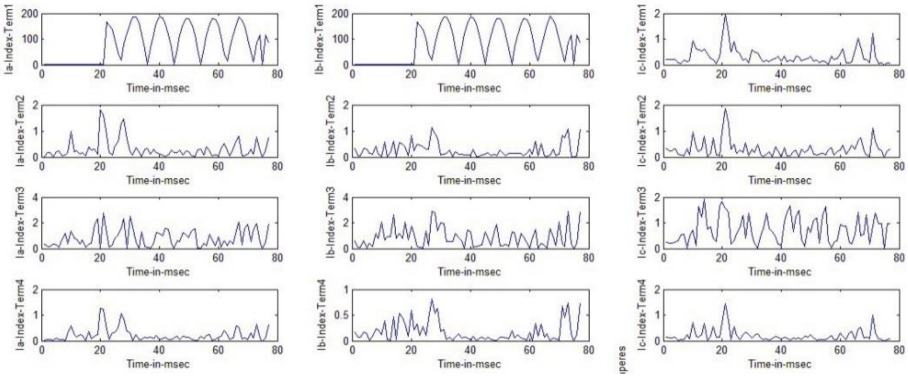

Fig. 3: Fault index variation of all phase currents at Bus1 to Bus 4 to detect fault terminal

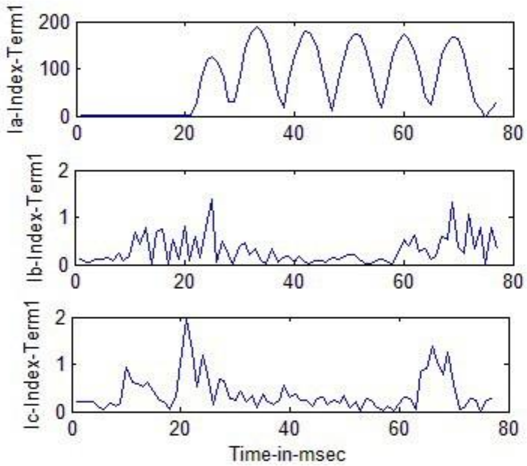

Fig. 4: Fault index variation of all phase currents at terminal1 at LG Fault on phase A

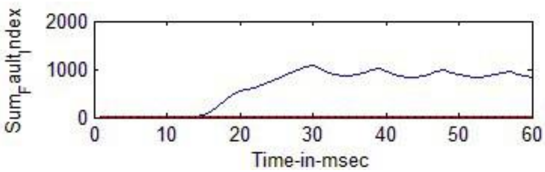

Fig. 5: Variation of the sum of detailed-coefficients phases currents at terminal1 at LG Fault on phase A

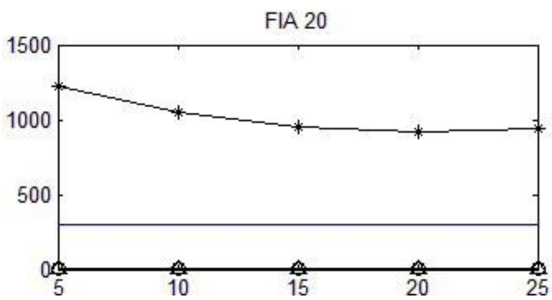

Fig. 6: Fault index variation from terminal1under LG fault at FIA20^0

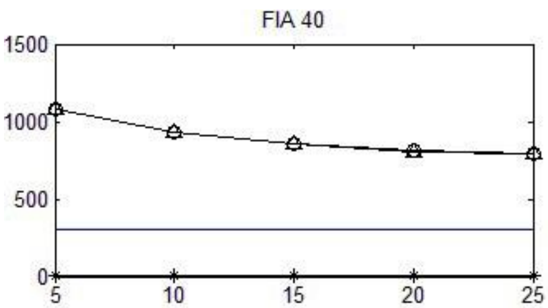

Fig. 7: Fault index variation from terminal1 under LL fault at FIA40^0

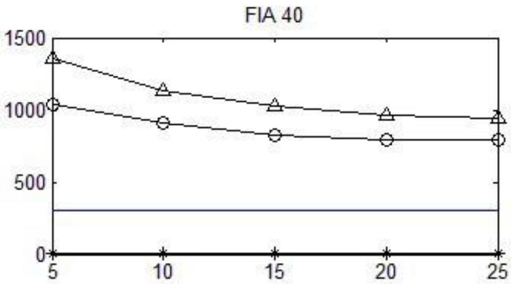

Fig. 8: Fault index variation from terminal1 under LLG fault at FIA40^0

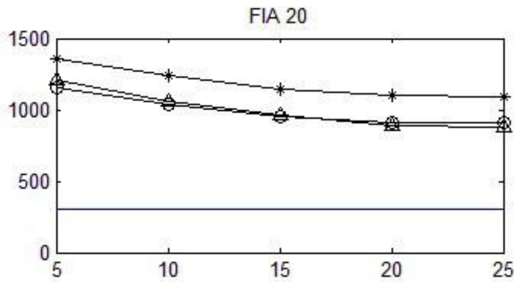

Fig. 9: Fault index variation from terminal1under LLLG fault at FIA20^0

Phase A&B to ground fault (LLG) at terminal2 which is illustrated in Fig. 10. Sum of detailed-coefficients of phase currents is shown in Fig. 11 and observed that LLG fault. To identify the type of fault, phases index values are above threshold values, it can be identified that the type of fault. Fig. 12 shows the LG fault on terminal2, the LLG fault on terminal2 as illustrated in Fig. 13 the LL fault on terminal2 as shown in Fig. 14, and the 3-Φ fault on terminal2 as shown in Fig. 15. Figs. 12-15 show the variation of fault index for transmission system LG, LL and LLG fault at various FIA's from terminal2.

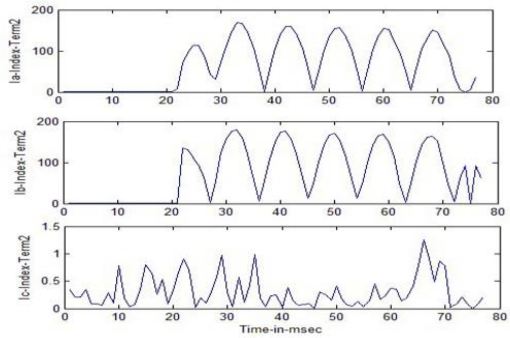

Fig. 10: Fault index variation of all phase currents at terminal2 at LLG Fault on A and B phase

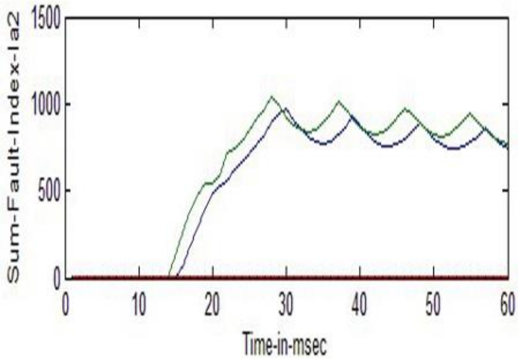

Fig. 11: Variation of the sum of detailed- coefficients phases currents at terminal2 at LLG Fault on A and B phase

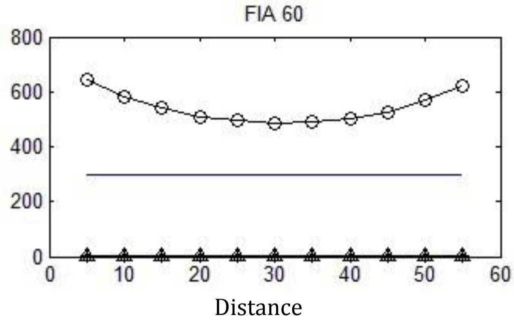

Fig. 12: Fault index variation from terminal2 under LG Fault at FIA60⁰

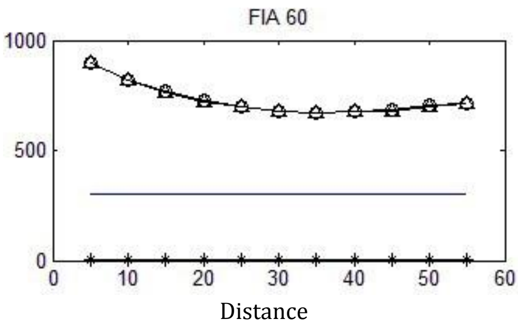

Fig. 13: Fault index variation from terminal2 under LLG at FIA60⁰

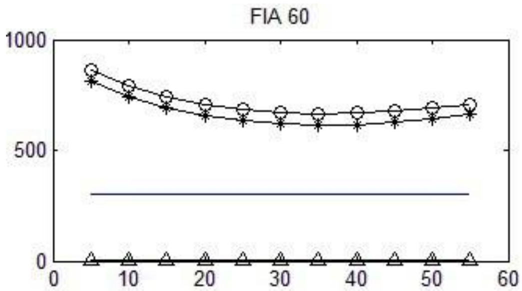

Fig. 14: Fault index variation from terminal2 under LLG fault at FIA40⁰

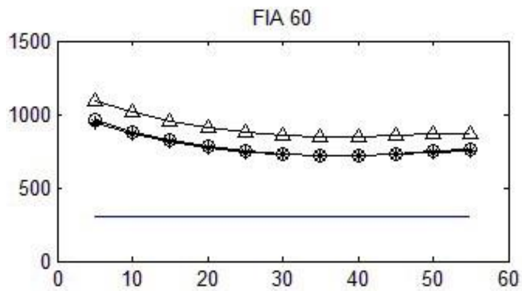

Fig. 15: Fault index variation from terminal 2 under LLLG fault at FIA20⁰

Phase A&B fault (LL) at terminal3 which is illustrated in Fig. 16. The Sum of detailed coefficients of phase currents is shown in Fig. 17 and observed that LL fault.

To identify the type of fault, phases index values are above threshold values, it can be identified that the type of fault. Fig. 18 shows the LG fault on terminal3, the LLG fault on terminal3 as illustrated in Fig. 19.

The LL fault on terminal3 as shown in Fig. 20, and the 3-Φ fault on terminal3 as shown in Fig. 15. Figs. 18-20 show the variation of fault index for transmission system LG, LL, and LLG fault at various FIA's from terminal3.

Phase B&C to ground fault on terminal4 which is illustrated in Fig. 21, Fig. 22 shows LG fault on terminal4, the LLG fault on terminal4 as illustrated in Fig. 23.

The LL fault on terminal4 as shown in Fig. 24, and 3-Φ fault on terminal4 as shown in Fig. 15. Figs. 22-25 show Fault index variation for transmission system LG, LL, and LLG fault at various FIA's from terminal4.

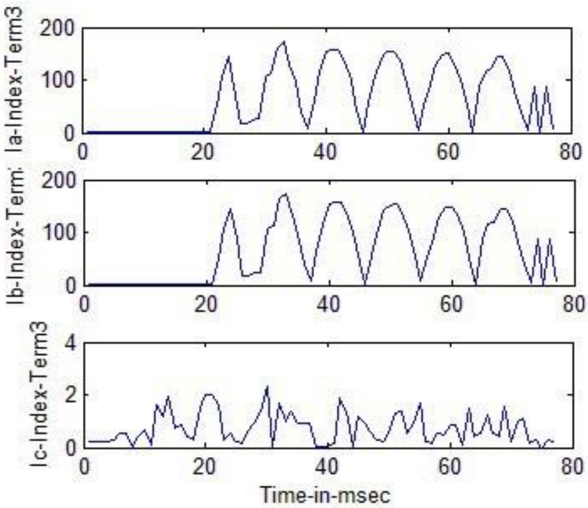

Fig. 16: Fault index variation of all phase currents at terminal3 at LL Fault on A and B phase

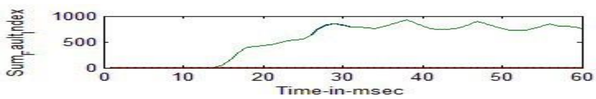

Fig. 17: Variation of the sum of detailed-coefficients phase currents at terminal2 at LL Fault on A and B phase

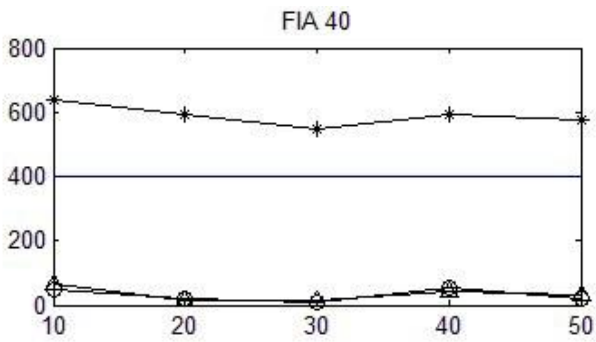

Fig. 18: Fault index variation from terminal3 under LG fault at FIA40⁰

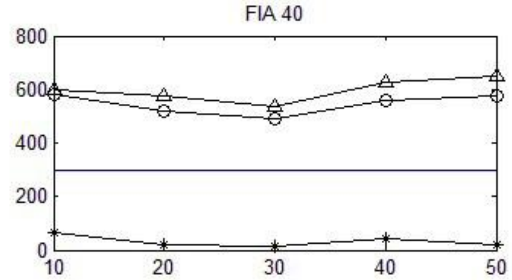

Fig. 19: Fault index variation from terminal3 under LLG fault at FIA40^0

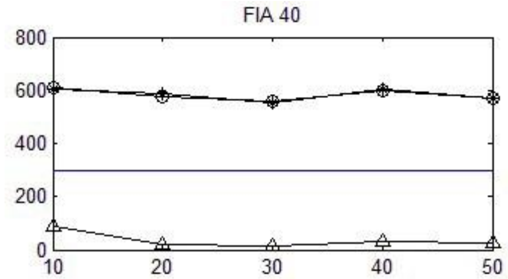

Fig. 20: Fault index variation from terminal2 under LL fault at FIA40^0

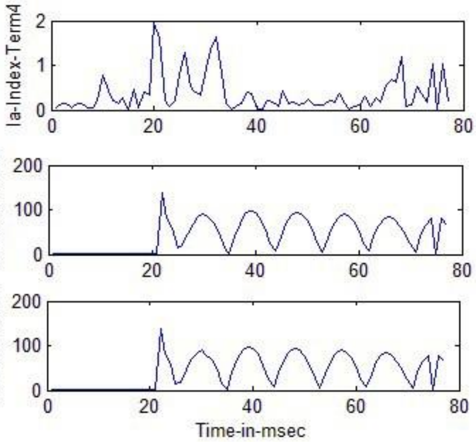

Fig. 21: Fault index variation of all phase currents at terminal4 at LL Fault on A and B phase

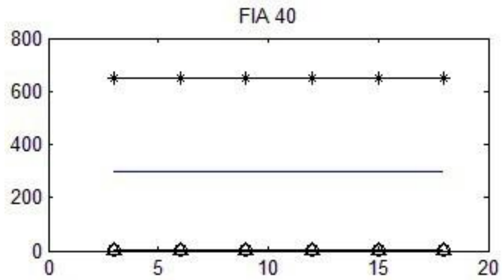

Fig. 22: Fault index variation from terminal4under LG fault at FIA40^0

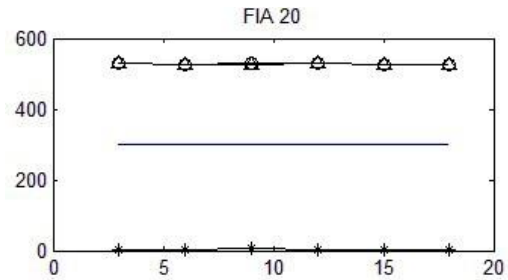

Fig. 23: Fault index variation from terminal4 under LL fault at FIA20^0

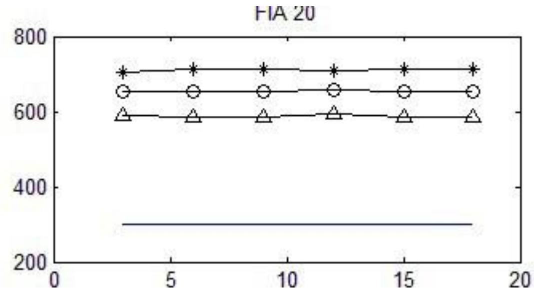

Fig. 24: Fault index variation from terminal4 under LLG fault at FIA20^0

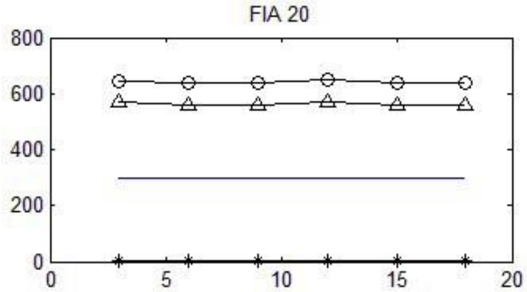

Fig. 25: Fault index variation from terminal 4 under LLLG fault at FIA20^0

5. Conclusions

The protection scheme must ensure the safe operation of the microgrid in both modes of operation,

i.e., the grid-connected mode and island mode. Due to the contribution of the host grid in grid-connected mode fault currents are large and Microgrids comprise Distributed Energy Resources (DERs) with LVdistribution systems having controllable loads which can operate with different voltage levels connected to the microgrid and operated in grid mode or islanding mode in a coordinated way of control. The provision of a properly reliable and coordinated protection scheme can reliably trip in the event of a fault within it. In this paper, the test system is created and simulated using the power system block set with SIMULINK software. Wavelet-based Multi-resolution Analysis is used for detection, discrimination, and location of faults on the transmission network. D1 detail coefficients of current signals using Mother Biorthogonal 1.5 wavelets are used to detect, discriminate, and location of the fault. The proposed protection scheme is found to be fast, reliable, and accurate for various types of faults on transmission networks with microgrids containing fuel cells, wind turbines, solar photovoltaics, and battery generation system.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

Chaitanya N, Sujatha P, and Sekhar KC (2017). Current controller based power management strategy for interfacing DG units to micro grid. International Journal of Electrical and Computer Engineering, 7(5): 2300-2308. https://doi.org/10.11591/ijece.v7i5.pp2300-2308

Ding M, Zhang Y, and Mao M (2009). Key technologies for microgrids-a review. In 2009 International Conference on Sustainable Power Generation and Supply, IEEE, Nanjing, China: 1-5. https://doi.org/10.1109/SUPERGEN.2009.5348218

Escudero R, Noel J, Elizondo J, and Kirtley J (2017). Microgrid fault detection based on wavelet transformation and Park's vector approach. Electric Power Systems Research, 152: 401-410. https://doi.org/10.1016/j.epsr.2017.07.028

Littler TB and Morrow DJ (1999). Wavelets for the analysis and compression of power system disturbances. IEEE Transactions on Power Delivery, 14(2): 358-364. https://doi.org/10.1109/61.754074

Makming P, Bunjongjit S, Kunakorn A, Jiriwibhakorn S, and Kando M (2002). Fault diagnosis in transmission lines using wavelet transform analysis. In IEEE/PES Transmission and Distribution Conference and Exhibition, IEEE, Yokohama, Japan, 3: 2246-2250.

Mallat SG (1989). A theory for multi resolution signal decomposition: The wavelet representation. IEEE Transactions on Pattern Analysis and Machine Intelligence, 11(7): 674-693. https://doi.org/10.1109/34.192463

Nikkhajoei H and Lasseter RH (2007). Microgrid protection. In 2007 IEEE Power Engineering Society General Meeting, IEEE, Tampa, USA: 1-6. https://doi.org/10.1109/PES.2007.385805

Oshaba AS and Ali ES (2014). Bacteria foraging: a new technique for speed control of DC series motor supplied by photovoltaic system. International Journal WSEAS Transactions on Power Systems, 9: 185-195.

Oudalov A, Fidigatti A, Degner T, Valov B, Hardt C, Yarza JA, and Lorentzou M (2009). Novel protection systems for microgrids. Final Version of Partial Report for WP C (TC2: Technical Requirements for network Protection) on More Microgrids EU-Project. Available online at: http://www.microgrids.eu/documents/688.pdf

Oudalova A and Fidigattibfd A (2011). Adaptive network protection in MICROGRID. Available online at: www.microgrids.eu/documents/519.pdf

Priyadharshini KM, Srinivasan S, and Srinivasan C (2015). Detection of power quality disturbances in micro grid connected power system. TELKOMNIKA Indonesian Journal of Electrical Engineering, 14(1): 9-15. https://doi.org/10.11591/telkomnika.v14i1.7232

Sudhir KS (2013). Wavelet based fault detection and ANN based fault classification in transmission line protection scheme. International Journal of Engineering Research and Technology, 2(5): 1492-1500.

Ustun TS, Ozansoy C, and Zayegh A (2011). A microgrid protection system with central protection unit and extensive communication. In 2011 10th International Conference on Environment and Electrical Engineering, IEEE, Rome, Italy: 1-4. https://doi.org/10.1109/EEEIC.2011.5874777

Wang XP, Li Y, and Yu YY (2011). Research on the relay protection system for a small laboratory-scale microgrid system. In 2011 6th IEEE Conference on Industrial Electronics and Applications, IEEE, Beijing, China: 2712-2716. https://doi.org/10.1109/ICIEA.2011.5976056