TELKOMNIKA Telecommunication Computing Electronics and Control
Vol. 20, No. 1, February 2022, pp. 173~184
ISSN: 1693-6930, DOI: 10.12928/TELKOMNIKA.v20i1.19652

Review of microgrid protection strategies: current status and future prospects

Zaid Alhadrawi[1], Mohd Noor Abduallah[1,2], Hazlie Mokhlis[3]
[1]Department of Electrical Engineering, Faculty of Engineering, University of Kufa, Najaf, Iraq
[2]Green and Sustainable Energy (GSEnergy) Focus Group, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Johor, Malaysia
[3]Department of Electrical Engineering, Faculty of Engineering, University Malaya, Kuala Lumpur, Malaysia

Article Info

Article history:

Received Jan 19, 2021
Revised Dec 17, 2021
Accepted Dec 25, 2021

Keywords:

Distributed generation
microgrid
Protection
Renewable energy

ABSTRACT

A microgrid is a developed form of a distribution system, which is integrated with a set of different types of distributed generation (DG) to supply local demand. In spite of that microgrids have many advantages as they increase reliability, raise efficiency, decrease feeder losses and voltage sag correction. However, there are many technical challenges faced, one of them is the protection of microgrid. Conventional protections have been made for radial distribution systems configuration. Where supplying source has one direction and the power flow is defined. The DG penetration converts the distribution network to a multi sources system causes a bidirectional power flow. Also, the most of DG uses a DC to AC converter which limit the fault current level. Therefore, a suitable protection scheme for microgrid ought to be designed to protect a microgrid from any disturbances may occur for both modes of operation grid-connected and islanded. The purpose of this paper is to summarize the challenges and problems facing microgrid protection. As well as the most strategies to date are presented with a discussion of their basic principles of operation to solve these problems. Finally, some conclusions and suggestions for microgrid protection in the future are presented.

Corresponding Author:

Mohd Noor Abduallah
Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia
Parit Raja, Batu Pahat, Johor, Malaysia
Email: mnoor@uthm.edu.my

1. INTRODUCTION

The microgrid can be defined as a distribution system that is integrated with a set of different types of distributed generation (DG) such as diesel engine, microturbine, fuel cells, storage batteries and renewable energy sources for supplying local demands. The microgrid can be operating in islanded or grid-connected mode for radial or loop configuration [1]. For grid-connected mode, the load in microgrid was supplied by the utility and microgrid sources. While during the islanded mode, only microgrid sources will be responsible for power generation.

Microgrid has many advantages over traditional systems where it can increase reliability by supplying the islanded network during the disturbance in the main grid. Also, it can mitigate overload problems from the grid and main grid maintenance is possible while the load supplied by DGs [2]. In spite of that, microgrid represents one of the most important solutions to problems of traditional generation-based fossil fuel, but there are many technical challenges faced acting as protection, voltage and frequency control.

The design of an appropriate protection scheme for microgrid is a major challenge for the microgrid operation. The penetration of DGs in traditional distribution system changes the protection schemes features due to the traditional distribution networks usually be the radial configuration with the unidirectional source. The DG units located in a microgrid can change fault current paths, lead in bi-directional power flows, increase fault currents and impact protective devices operations. In addition to fault current levels are low because of inverter-based sources is connected in islanded microgrid [3]–[7].

This paper aims to summarize the challenges and problems facing microgrid protection in addition to the solution suggested so far, as the solutions classified into seven schemes based on the principles of operation with a discussion of their disadvantages. The organization of the paper is as follows: section 2 describes the impact of DGs on microgrid protection. Section 3 outlines the existing protection schemes. Section 4 discusses the general features of protection schemes. The paper is finally concluded in section 5 with some recommendations for the microgrid protection in the future.

2. IMPACT OF DGs ON THE MICROGRID PROTECTION

The previous studies show that conventional protection for distribution networks have faced many challenges when the DGs are installed. The conventional protections have been made for radial distribution system configuration, where supplying source is only one and the power flow is defined. The installation of DGs to the distribution system leads to multi-sources of the current which alter the currents flow during a fault in a different section of the feeder circuit, besides increase the fault current level. The most common challenges mentioned in previous studies are as follows [8]–[16]:

2.1. The different in fault current level

During the growing penetration of DGs to the distribution network, which previous to that period have a load only without any local power generation, where, only one power source supplies the fault current. While, installation of DGs leading to an increased fault level. It is largely difference in the fault current level in the two operation modes of a microgrid as shown in Figure 1.

In grid-connected mode, the fault current is supplied by the main grid and DG. While in islanded mode, the microgrid is disconnected from the utility. Therefore, only the DG feed fault current. The complexity is that these DGs have a limited fault current, typically this fault current is about twice their rated current. This is not enough to trip conventional protective devices and therefore other protection strategies have to be established. Where I_f is the fault current, I_M is the main grid current and I_{DG} is the DG current

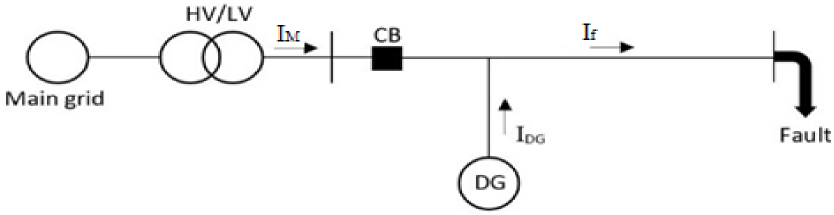

Figure 1. The contribution of main grid and DG for fault current

2.2. False tripping

Unnecessary disconnection or false tripping happen when the relay operates for faults in an outside zone of protection. In grid-connected operation mode of microgrid, when a DG is connected to one of the microgrid's feeders and an adjacent feeder has a fault, then in such a situation, if the DG size is adequately large, a part of the fault current is supplied by the DG. Which leads to override the pick-up current value of the relay that installs in the healthy feeder. Then the trip will happen before the responsible relay is operate as shown in Figure 2.

2.3. Blinding of protection

The existence of DGs can prevent feeder relay to operate properly because the contribution of the utility grid decreases as a result of an increasing total impedance. Therefore, the fault current remains bellow the pick-up current of the feeder relay, where the pick-up current depends on the impedance as shown in Figure 3. This can lead to the feeder relay being delayed or no tripping in the worst situation. This case is called blinding of protection or protection underreach.

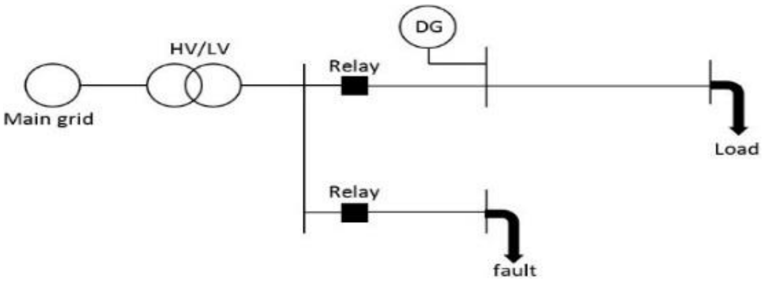

Figure 2. Principle of false tripping

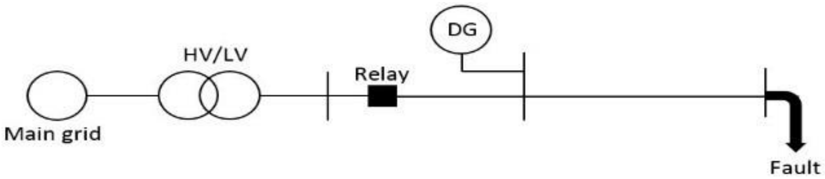

Figure 3. Principle of blinding of protection

2.4. Failure of auto-recloser

Auto-reclosing is a protective device that has a group of functions are detecting, fault clearing and reclosing in one combined unit that is generally used in distribution networks with overhead lines. The faults on these lines often are temporary faults. The auto-recloser opens the line for a short period to allow the fault to remove. After a time delay, the line is excited again by the auto-recloser. When the fault is cleared the line can remain in serving else the auto-recloser opens the line.

DG units can disturb the auto-reclosers operation significantly. During the open period of the auto-recloser, the DG unit can continue to feed current to the faulted feeder thus exciting the arc and the temporary fault becomes a permanent fault. Also, the coordination between recloser and fuse will be missed. Temporary faults will treat as permanent faults and remove by the fuse instead of the recloser.

2.5. Effect of different types of DG on short circuit current

As per the attributes of DG associating with the distribution network, DG will be classified into traditional rotating DG type and inverter-based DG type, and the variation of DG types lead to different transient fault performance [17]. The inverter-based DG use an inverter circuit as a DC to AC converter to connect to the distribution network, it is therefore unable to have too many short circuit currents for the limitation of inverter-based DG output. Typically, fault currents level provided by inverter-based DG is merely 2–3 times of rated current. While, traditional rotating DG type can provide more current than inverter-based DG type. Hence, research on various types of DG linked to the distribution network has major importance.

3. EXISTING PROTECTION STRATEGIES IN MICROGRID

The microgrid protection should respond to fault for both the utility grid and microgrid. If a utility grid was exposed to a fault, the microgrid must be isolated from the rest of the network. This causes to the islanded operation of the microgrid. When a fault happens within the microgrid, the microgrid protection isolates the minimum possible faulted area of a microgrid to eliminate the fault. In the last years, different strategies have been suggested to present a reliable protection scheme for microgrids.

3.1. Adaptive protection schemes

Adaptive protection was known as an online activity that adjusts the best protective response to an alteration in microgrid situations or requirements [18]. It has two groups of relay settings, the first for grid-connected while the second for islanded mode. Where the relay settings will be adjusting automatically according to the microgrid operating mode [19]. The magnitude of fault current (I) is within the two ranges as shown in (1) and (2).

$$Ii \leq I < Ig \quad (1)$$

$$I \geq Ig \quad (2)$$

Where Ii is the threshold value of positive current in the island mode and Ig is the threshold value of positive current in the grid-connected mode [20]. Sitharthan *et al.* [21] monitored the microgrid by a developed adaptive protection scheme and immediately updates relay depending on the different that happens in the network. The adaptive overcurrent (OC) protection scheme in [22] based on a programmable Logic method, where the math operators and programmable logic was used instead of the stored functions in the relay. The work in [23] updated relays trip features based on local information to detect operation mode of microgrid, grid-connected or islanded, and the faulted section. The scheme in [24] used grouping similar inverse time OC settings of relays to protects feeders. Another adaptive protection strategy with a traditional differential protection strategy has been implemented in [25].

Swathika and Hemamalini [26] proposed a central protection center which has three functions adaptively monitor the currents of feeder constantly, detect OC fault happening and detect faulted feeder and suitable settings for a relay to help fault clearance. The work in [27] automatically change the protection settings of all OC, which used the optimum protection settings instead of precalculated setting groups and applied them to the relays directly.

Also, an adaptive directional OC relaying based on the positive sequence components (PSQ) and negative sequence components (NSQ) superimposed currents for protection of microgrid has been proposed in [28]. Ma *et al.* [29] utilized a steady-state fault current to adjust the main and backup protection settings criteria. The researchers in [30] combined the characteristics of both time and instantaneous OC elements for maintaining recloser fuse coordination in a microgrid. Also, they used a microprocessor-based recloser instead of the existing recloser. The new digital relay in [31] based on the ratio of feeder current to recloser current to modify the time-dial setting of the relay, this study aims to avoid mis-coordination between recloser and fuse.

The paper [32] introduced a practical overcurrent based on characteristics of the feeder and the location of the intelligent electronic devices IEDs, in addition to an adaptive frequency approach proposed to avoid increase load effects in low inertia islanded microgrids. Habib *et al.* [33] proposed an adaptive protection scheme to increase flexibility against communication outages. Although the adaptive scheme has the flexibility of adaptive relays and the capability to automatically adjust the settings of it in response to the status of DGs, operational mode of the microgrid and active networks management, however, it has disadvantages:

- All possible configurations of a microgrid should be confident
- Difficulties of calculations associated with changed of microgrid operation mode, unbalanced load and transients during disconnection or connection of DG units
- The need for a realible and fast communication link, relays replacement and synchronized measurement device may involve high cost
- The scheme was not suttable for high impedance faults (HIF)

3.2. Signal processing protection schemes

A transient disturbance that occurs in microgrid represents a signal with complex time-frequency structures. This transient disturbance is often distinguished with high frequency oscillatory, short duration, non-stationary, non-periodic, impulse superimposed contents and fast decaying. Therefore, the waveform magnitude is generally not a suitable indicator of the fault condition. Thus, signal processing are necessary to sort faulted and normal states.

- Filtering of analog signal: firstly, the input signals passes during a low pass filters where the frequencies bellow than f_k are passes the frequencies above that are eliminates. The cut-off frequency f_c of the filter should meet the following requirements.

$$f_k < f_c \leq \frac{f_s - f_k}{3} \tag{3}$$

Where f_k is the highest frequency of the component and f_s is a sampling frequency.

- Sampling process: To allow the components that are essential for relaying decisions to be reproduced, the sampling frequency choosing f_s should not be too low. Then again, it should not be excessively high, to prevent needless burden for the digital processing. According to Shannon–Kotielnikov theorem, at least two samples of signal should be taken within the signal period to avoid loss of information. If the reproduced component has the frequency f_k , the sampling frequency should be:

$$f_s \geq 2f_k \tag{4}$$

The signals convert to time discreet after the sampling, but the qualities stay still analog. Therefore, an A/D converter is used. In multi channels modern digital relay, One A/D converter is used to processing a number of signals.

- Digital signal processing: to detect the faulted zone and issue the final decision, the sample signal is processing digitally by calculation algorithms [34]. The present common methods of signal processing protection schemes are:

3.2.1. Fourier transform (FT)

Fourier Transform is a mathematical function that decomposes a waveform that takes a time-based pattern into the frequencies. The papers [35]–[37] employed a fourier transform to estimate the fundamental component of the inputs. Bukhari *et al.* [35] used the fundamental components of three phase currents and voltages as the input to the fuzzy system based on discrete fourier transform to detect and classify the faults. Another research [36] designed a numerical relay uses a fast recursive discrete fourier transform algorithm. Also, the relay is included with the fuzzy module for getting the best protection settings. On the other hand, a data mining based-intelligent differential protection presented in [37].

3.2.2. Wavelet transform (WT)

The papers [1], [38]–[41] used a microprocessor relay based on Wavelet Transform to protect microgrid from different faults that may occur. A new protection scheme was developed in [1] for a microgrid with an inverse interface DG employing the wavelet transform and data mining model. At first, the current is preprocessed to extricate the best effective specifications that contain the transient information. Then, the wavelet-based specifications are utilized to construct the data mining models for conclusive relaying decisions.

The work in [38] treated using wavelet transform to result distinguishing features between healthy and faulty case as well as between grid-connected and isolated mode to fulfill the different tasks of relaying scheme. The studies in [39] and [40] employed the wavelet packet transform (WPT) to identify a fault in a microgrid. Where the proposed protection in [39] based on utilizing a single stage wavelet packet transform to extract the first level high frequency contents from the categorized transient disturbance in d-q-axis current components. The digital relays in [40] is established based on the second level high frequency sub bands extracted from the d–q-axis current components that is flowing through each point of the network. Another work [41] employs a discrete wavelet transform in protective relays to extract statistical features of current measurements sampled.

3.2.3. Mathematical morphology (MM)

Another time domain signal processing technique is mathematical morphology (MM) used in [42] and [43] for faults disclosure in a microgrid. Where a novel protection strategy for microgrid was presented in [42] based on mathematical morphology. The morphological wavelet was utilized for faults disclosure in a microgrid. Consequently, current restore from both sides of the feeder is processed by a morphological wavelet after a prophecy lifting scheme to have the details of signals. The details of signals diversity and their criterion are computed to have a primary protection scheme for the feeder. Also, an improved mathematical morphology technology based on the initial current traveling wave was utilized in [43], with simplified polarity disclosure and new logics inserted for meshed distribution networks and feeders with individual end measurement.

3.2.4. Hilbert Huang transform (HHT)

The Hilbert–Huang transform (HHT) is a non-stationary signal processing algorithm that is efficient and very reliable for the objective of fault detection [44]. The references [44]–[46] used this algorithm to investigate protection for the microgrid. Gururani *et al.* [44] used it in the status of differential protection. The assessment of the efficiency of the proposed scheme is achieved in comparison to differential current and S-transform. Also, the work in [45] based on HHT and techniques of machine learning which presented a novel microgrid protection scheme for extraction and selection of useful differential merits. Another protection scheme based on superimposed reactive energy was proposed in [46]. The suggested scheme used microprocessor relay with a HHT to detect fault occurrences and to isolate the faulted sections in a special way.

3.2.5. S-transform

S-transform is defined as a time-frequency analysis method, derived from fourier transform and Wavelet transform. It is used in signal processing of non-stationary signal [44]. This method applies in [47] and [48]. The study in [47] presented a differential scheme for microgrid protection which uses S-transform. Firstly, the current at certain buses is processed thr1ough S-transform to make time-frequency features. The fault current signals are processed and differential energy is detected to distinguish the type of fault in the microgrid at grid-connected and islanded mode. While in [48], S-transform proposed to combine with the decision tree to detect and classify fault and in the microgrid. Even though the signal processing scheme is able to protect the microgrid for both modes of operation, but there are several disadvantages

- The scheme required accurate signal synchronization and a very high sampling frequency which is unpractical because of the absence of economical digital signal processing (DSP) hardware
- Scheme suffers from the high computational burden leading to a slower response
- The system faces problems in the protection of microgrid against HIFs

3.3. Differential protection schemes

The traditional differential protection compares the current magnitude at two ends of the protected equipment and will operate when the difference between these currents exceeds a threshold value. Many researchers have used this type of protection to protect the microgrid. Consider a scheme that is illustrated in Figure 4. The current entering in the first end (I_1) and the current leaving the second end (I_2) have to be similar. But during fault, a clear different between them. Otherwise, an algebraic sum of the two currents that reach the protected apparatus could be generated as presented in (5) [20].

$$\boldsymbol{I_r = I_1 + I_2} \tag{5}$$

A comprehensive digital relay based protection has been introduced in [49] for the protection of microgrids. The introduced method utilized one-slope differential relay characteristic for protection feeders based on a current data in both sides of the protected feeder is amassed and fault occurrence is distinguished based on their variation. A new communication-based protection was proposed in [50]. The proposed scheme used a differential protection scheme that relies on symmetrical components. A proposed method in [51] employed Rogowski coil sensors to detect polarities of the fault current transients, it is possible to determine in case of a fault within the protected zone by comparing the initial polarities of the transients current measured at two sides of the zone.

Kar [52] suggested a fuzzy rule base approach to protect the microgrid. The suggested scheme includes main and backup protection which begins with preprocessing of the retrieved voltage and current signals at both sides of the faulted feeder and neighboring feeder to calculate the differential merits.

Despite the differential scheme appropriate for the microgrid protection and can act as quickly as within five milliseconds, also, the threshold of differential scheme can be easily modified, and it can be adapted to both the grid-connected mode and islanded mode, however there are some disadvantages:

- The need for a secondary protection scheme when the communication system fails
- The need for protective device at each end of lines and communication links for receiving current measurements from both line ends to make it expensive
- Difficulties may be faced in an unbalance system or load transients during connection and disconnection of DGs may cause some problems

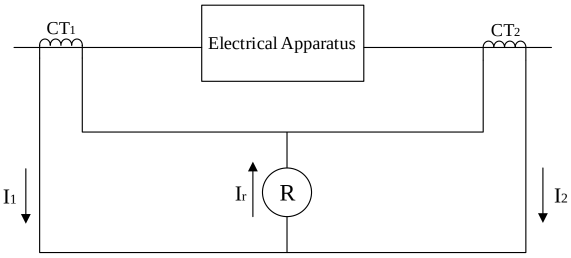

Figure 4. Differential Protection Principle

3.4. Overcurrent protection scheme

The obvious increasing in currents during the fault can be used to detect the faults by overcurrent devices. The time operating characteristics of the relays defines in (6), this formula based on IEC and ANSI/IEEE Standards:

$$t = \frac{k\beta}{(I/I_s)^{\alpha}-1} + L \tag{6}$$

where: t = operating time of relay in seconds; k = time multiplier setting; I =fault current level in amps; I_s = pick-up current; L =constant. The constants α and β determine the slope of the relay characteristics.

Some of the researcher employed the overcurrent devices to protect the microgrid. To achieve dependability and security of microgrid operation in islanded mode. Lai *et al.* [53] proposed a comprehensive protection strategy. This strategy used a microprocessor relay to avoid superfluous loss of critical loads and DGs. The proposed study in [54] used a fault diagnosis and clearing strategy method was for symmetrical and unsymmetrical faults in a meshed distribution system. A directional overcurrent and earth fault have been investigated in [55] to protect the microgrid.

The reference [56] developed a new directional relay to prevent mis-operation of protective devices which utilized negative sequence impedance magnitude and the angle to detect the direction of unsymmetrical faults. While it used the positive sequence impedance magnitude along with the positive sequence current magnitude and torque angle for symmetrical faults. The proposed protection scheme in [57] is a digital relay that includes different protection functions to protect the microgrid against various types of faults embedding high impedance fault in both modes of operation.

Two concepts for a voltage-controlled DG unit was employed in [58]. The first is an overcurrent protection scheme that depends on voltage measurements which includes fault detection, fault current limiting scheme, fault current determination, and controller restoration mechanisms. The second is an overload protection scheme. The work in [59] proposed a protection system that aims to improve microgrid reliability and adaptability operation. This scheme used parameters of voltage, current and angle phase with communication links to protect the microgrid. Despite the overcurrent scheme is capable of protecting the microgrid which has high fault current, however, the scheme faces many challenges:

- Since most of the DGs are equipped with current limiting device, the fault current only lasts for a short period of time and it is beyond the capability of overcurrent protection to trip the fault in a short period of time
- adopting the overcurrent protection under both scenarios of microgrid modes (grid-connected and islanded)
- the variety of the operation of the operation of DGs determines the complexity of the overcurrent protection setting

3.5. Symmetrical components protection scheme

Symmetrical components protection schemes used a sequence component of currents and voltages in the microgrid to diagnose the faulted zone. The symmetrical components method is applicable to resolve an unbalanced three phase system into three balanced systems of phasors, where the system decompose into three sequence networks:

- Zero sequence components
- Positive sequence components
- Negative sequence

The matrix form of the three phase voltage and current sequence components of are discribed in (7) and (8).

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} \tag{7}$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} \tag{8}$$

The paper [60] used the sequence components of currents to detect the fault in the microgrid. Where the zero-sequence component of the current was considered in case of a single line to ground fault, while the negative sequence component of the currents was considered for the double line faults. Another microgrid protection scheme based on the positive sequence component was presented in [61]. The scheme used phasor measurement units and designed a microprocessor-based relay with a communication system.

A three-version software unit has been suggested in [62] for the protection of microgrid. The three program versions used for detecting fault current in the microgrid are symmetrical components and overcurrent protection. Lin *et al.* [63] proposed a protection scheme based on fault components and the dividing of microgrid into several zones depend on the acceptable arrangement of the critical load with distributed generation and energy storage unit. This strategy provides acceptable protection for the microgrid, but there are disadvantages:

- When zero sequence current was used, the scheme required an additional element (grounding transformer) inside the microgrid to determine the direction of the fault
- The scheme was not able to protect the microgrid against HIFs
- The scheme required complete upgrading of the protection device currently used in the microgrid

3.6. Fault current limiter protection schemes

Fault current limiter (FCL) is presented to minimize the effect of DGs on the present protection schemes through the fault. FCL allows normal power flow during normal operation, however limiting the magnitude of fault current under the fault situation. Also, FCLs have a very small resistance and it does not affect frequently the efficiency of the power system [64]. For symmetrical three-phase fault, when the capacity of the circuit breaker is less than the transient and steady state fault current, then the FCL should limit the excesses current. This leads to the constraint on FCL impedance Z_l (9).

$$Z_l > \frac{V_{ph}}{I_f} - Z_u \quad (9)$$

Where V_{ph} is phase voltage, Z_u is the impedance of the circuit under fault condition and $I_c$is the short circuit current.

The maximum value of impendence Z_m that initiates the operation of the FCL (10).

$$Z_m < \frac{V_{ph}}{2I_n} - 2Z_l \quad (10)$$

Where I_n is the normal current A fault current limiter was used in [65] in series with the utility, in synchronism with directional OC relays to solve the problem of protection coordination in distribution networks equipped with a synchronous generator. Also, the paper [66] proposed a generalized approach to calculate a protection coordination index taking into consideration multiple DG locations. Also, the paper utilized FCLs as a solution for enhancing the protection coordination index.

The paper [67] investigated the optimal using of FCLs to keep the directional overcurrent relay coordination to operate without resetting the relays regardless of DGs state. The FCLs location and sizing problem is formulated as a constrained to maintain the overcurrent relay coordination at a minimum cost of possible FCLs. A unidirectional fault current limiter (UFCL) was proposed in [68] to obtain an appropriate interaction between the downstream and upstream. A superconducting fault current limiters (SFCLs) was used in [69] to mitigate the impact of synchronous machine based DG integration on the radial fuse recloser protection configuration.

He *et al.* [70] suggested a modified flux coupling type super-conducting fault current limiter (SFCL) to investigates the coordination of relay protection in the microgrid and improve the DGs fault capability. Further, they proposed the directional overcurrent and differential relay for the microgrid protection. Also, [71] modified SFCL to a hybrid SFCC so that be used in microgrids. The SFCC is autonomous from the monitoring of utility technology and it uses an operation feature. Although FCLs contribute to reducing the effect of DGs on the microgrid, however, several disadvantages will appear:

- Each microgrid operational topology requires calculations in order to decide the best locations of installing FCLs
- FCL is generally expansive it is possible to add FCL in all network to use each one in necessary situations
- The determination of the FCL impedance value is difficult for the microgrids with high penetration of DGs due to the mutual influence of DGs

4. DISCUSSION AND ANALYSIS

Although the research aforementioned has many positives, some of them neglected important aspects in the microgrid configuration. Where they used only synchronous generators and ignored the DG based inverter interface despite its widespread and has a significant impact on the protection system because of the limited fault current of this DG type. Others did not take into account the protection system should be able to protect the microgrid of grid-connected and islanded modes and only designed protection for the islanded mode.

The technical challenges related to adaptive protection scheme are the protective devices need for updating and reliable and fast communication links that require high cost. Differential protection schemes require a communication links which is relatively expensive. As well communication links may be failed, therefore the backup protection necessary.

Some challenges may occur during the transient, when the DGs are connected or disconnected, and unbalanced system. One of the most important issues is the time of tripping should be as fast as possible to avoid equipment damage. This probability increases when signal processing or sequence component schemes used due to the process of signals pass through many stages before making a decision to tripping the faulted zone. After a detailed review of the protection schemes reported in the literature, the microgrid protection scheme in the future should have the following characteristics:

- Overcoming the problems to coordinate a large number of series protection device
- Reducing the burden of computing and units of communication
- Taking into consideration the two microgrid operating modes: grid-connected and isolated
- Identifying and detecting the faulty microgrid line during high inverter-based DG penetration
- The ability to cope with radial and loop configuration and no need change the protection device with each one

5. CONCLUSION AND FUTURE RESEARCHES

Penetration of DGs into distribution network causing many problems such as change the level of fault current, unnecessary disconnection, blinding of protection and failure of auto-recloser. Therefore, the traditional protection system cannot be utilized to protect microgrid. Many protection strategies and solutions are reviewed in recent literature to solve the protection problems. Previous studies have shown that some of the protection strategies modified the current protection system by controlling the fault current or re-coordinating protection devices. These strategies are useless with an increasing number of DGs or their variety. Others used new protection strategies but did not meet the standards for the protection system such as the speed of operation, simplicity, reliability, sensitivity, redundancy, selectivity and consistency. In addition, their implementation is very expensive. Differential protection schemes are the ideal solution but they require a communication links which is relatively expensive. As well communication links may be failed, therefore the backup protection necessary. In future works, the protection for microgrid requires a comprehensive scheme to be able to protect the system under all possible circumstances. It should be taken into consideration the mode of operation, the type of DG, topology of microgrid, fault types and cost. The development of nanotechnology can be employed in order to produce protective devices with high accuracy and low cost.

ACKNOWLEDGEMENTS

The authors would like to thank Universiti Tun Hussein Onn Malaysia (UTHM) for supporting this project under Multidisciplinary Research Grant Vot No. H 505.

REFERENCES

[1] D. P. Mishra, S. R. Samantaray, and G. Joos, “A combined wavelet and data-mining based intelligent protection scheme for microgrid,” *IEEE Transactions on Smart Grid*, vol. 7, no. 5, pp. 2295–2304, Sep. 2016, doi: 10.1109/TSG.2015.2487501.

[2] IEEE Standards Coordinating Committee 21, *IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems*, New York, NY, USA: IEEE, Jul. 2011. [Online]. Available: https://web.nit.ac.ir/~shahabi.m/M.Sc%20and%20PhD%20materials/DGs%20and%20MicroGrids%20Course/Standards/IEEE%20Std%201547/IEEE%20std%201547.4_2011.pdf

[3] S. Mirsaeidi, D. M. Said, M. Wazir Mustafa, M. H. Habibuddin, and K. Ghaffari, “Progress and problems in micro-grid protection schemes,” *Renewable Sustainable Energy Reviews.*, vol. 37, pp. 834–839, Sep. 2014, doi: 10.1016/j.rser.2014.05.044.

[4] A. A. Memon and K. Kauhaniemi, “A critical review of AC Microgrid protection issues and available solutions,” *Electric Power System Research*, vol. 129, pp. 23–31, Dec. 2015, doi: 10.1016/j.epsr.2015.07.006.

[5] S. A. Hosseini, H. A. Abyaneh, S. H. H. Sadeghi, F. Razavi, and A. Nasiri, “An overview of microgrid protection methods and the factors involved,” *Renewable and Sustainable. Energy Reviews.*, vol. 64, pp. 174–186, Oct. 2016, doi: 10.1016/J.RSER.2016.05.089.

[6] B. J. Brearley and R. R. Prabu, “A review on issues and approaches for microgrid protection,” *Renewable and Sustainable. Energy Reviews*, vol. 67, pp. 988–997, Jan. 2017, doi: 10.1016/j.rser.2016.09.047.

[7] P. H. A. Barra, D. V. Coury, and R. A. S. Fernandes, “A survey on adaptive protection of microgrids and distribution systems with distributed generators,” *Renewable Sustainable. Energy Reviews.*, vol. 118, pp. 1–16, Feb. 2020, doi: 10.1016/j.rser.2019.109524.

[8] K. Kauhaniemi and L. Kumpulainen, “Impact of distributed generation on the protection of distribution networks,” in *Eighth IEE International Conference on Developments in Power System Protection*, vol. 1, pp. 315–318, Apr. 2004, doi: 10.1049/cp:20040126.

[9] J. Morren and S. W. H. D. Haan, “Impact of distributed generation units with power electronic converters on distribution network protection,” *IET 9th International Conference on Developments in Power Systems Protection (DPSP 2008)*, pp. 663–668, 2008, doi: 10.1049/cp:20080118.

[10] A. Z. Adnan, M. E. Yusoff, and H. Hashim, "Analysis on the impact of renewable energy to power system fault level," *Indonesesia Journal of Electrical Engineering and Computer Science*, vol. 11, no. 2, pp. 652–657, 2018, doi: 10.11591/ijeecs.v11.i2.pp652-657.

[11] P. Sudhakar, S. Malaji, and B. Sarvesh, "Reducing the impact of DG on distribution networks protection with reverse power relay," *Materialstoday Proceedings*, vol. 5, no. 1, pp. 51–57, 2018, doi: 10.1016/j.matpr.2017.11.052.

[12] A. Arafa, M. M. Aly, and S. Kamel, "Impact of Distributed Generation on Recloser-Fuse Coordination of Radial Distribution Networks," in *Proceedings of 2019 International Conference on Innovative Trends in Computer Engineering, ITCE 2019*, , pp. 505–509, Feb. 2019, doi: 10.1109/ITCE.2019.8646557.

[13] S. E. Razavi *et al.*, "Impact of distributed generation on protection and voltage regulation of distribution systems: A review," *Renewable Sustainable Energy Reviews*, vol. 105, pp. 157–167, May 2019, doi: 10.1016/j.rser.2019.01.050.

[14] A. Yazdaninejadi, A. Hamidi, S. Golshannavaz, F. Aminifar, and S. Teimourzadeh, "Impact of inverter-based DERs integration on protection, control, operation, and planning of electrical distribution grids," *The Electricity Journal*, vol. 32, no. 6, pp. 43–56, Jul. 2019, doi: 10.1016/j.tej.2019.05.016.

[15] J. Jia, G. Yang, A. H. Nielsen, and P. R-Hansen, "Impact of VSC Control Strategies and Incorporation of Synchronous Condensers on Distance Protection Under Unbalanced Faults," *IEEE Transactions on Industrial Electronics*, vol. 66, no. 2, pp. 1108–1118, Feb. 2019, doi: 10.1109/TIE.2018.2835389.

[16] R. Mutambudzi and A. K. Raji, "Impact of Distributed Generation on the Electric Protection System," *SSRN Electronic Journal*, 2019, doi: 10.2139/ssrn.3658914.

[17] N. Zhou, X. Lei, X. Jing, X. He, and Z. Jiao, "Study on the Influence of Distribution Generation on Over Current Relays in Distribution Networks," *Proceedings of the 3rd International Conference on Advances in Energy and Environmental Science 2015*, pp. 989–994, Jul. 2015,doi: 10.2991/icaees-15.2015.182.

[18] M. Awaad, S. F. Mekhamer, and A. Y. Abdelaziz, "Design of an adaptive overcurrent protection scheme for microgrids," *International Journal of Engineering, Science and Technology*, vol. 10, no. 1, pp. 1–12, 2018, doi: 10.4314/ijest.v10i1.1.

[19] L. Che, M. E. Khodayar, and M. Shahidehpour, "Adaptive protection system for microgrids: Protection practices of a functional microgrid system," *IEEE Electrification Magazine*, vol. 2, no. 1, pp. 66–80, Mar. 2014, doi: 10.1109/MELE.2013.2297031.

[20] Z. Alhadrawi, M. N. Abdullah, and H. Mokhlis, "An adjustable differential protection scheme for microgrids with inverter-based distributed generation," *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 9, no. 1 .4, pp. 664–672, 2020, doi: 10.30534/ijatcse/2020/9391.42020.

[21] R. Sitharthan, M. Geethanjali, and T. K. S. Pandy, "Adaptive protection scheme for smart microgrid with electronically coupled distributed generations," *Alexandria Engineering Journal*, vol. 55, no. 3, pp. 2539–2550, Sep. 2016, doi: 10.1016/j.aej.2016.06.025.

[22] E. C. Piesciorovsky and N. N. Schulz, "Comparison of Programmable Logic and Setting Group Methods for adaptive overcurrent protection in microgrids," *Electrical Power System Research*, vol. 151, pp. 273–282, Oct. 2017, doi: 10.1016/j.epsr.2017.05.035.

[23] P. Mahat, Z. Chen, B. B-Jensen, and C. L. Bak, "A Simple Adaptive Overcurrent Protection of Distribution Systems With Distributed Generation," *IEEE Transactions on Smart Grid*, vol. 2, no. 3, pp. 428–437, Sep. 2011, doi: 10.1109/TSG.2011.2149550.

[24] E. C. Piesciorovsky and N. N. Schulz, "Fuse relay adaptive overcurrent protection scheme for microgrid with distributed generators," *IET Generation, Transmission & Distribution*, vol. 11, no. 2, pp. 540–549, Jan. 2017, doi: 10.1049/iet-gtd.2016.1144.

[25] T. S. Ustun and R. H. Khan, "Multiterminal Hybrid Protection of Microgrids over Wireless Communications Network," *IEEE Transactions on Smart Grid* vol. 6, no. 5, pp. 2493–2500, Sep.2015, doi: 10.1109/TSG.2015.2406886.

[26] O. V. G. Swathika and S. Hemamalini, "Prims-Aided Dijkstra Algorithm for Adaptive Protection in Microgrids," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 4, no. 4, pp. 1279–1286, Dec. 2016, doi: 10.1109/JESTPE.2016.2581986.

[27] F. Coffele, C. Booth, and A. Dysko, "An Adaptive Overcurrent Protection Scheme for Distribution Networks," *IEEE Transactions on Power Delivery*, vol. 30, no. 2, pp. 561–568, Apr. 2015, doi: 10.1109/TPWRD.2013.2294879.

[28] H. Muda and P. Jena, "Superimposed Adaptive Sequence Current Based Microgrid Protection: A New Technique," *IEEE Transactions on Power Delivery*, vol. 32, no. 2, pp. 757–767, Apr. 2017, doi: 10.1109/TPWRD.2016.2601921.

[29] J. Ma, X. Wang, Y. Zhang, Q. Yang, and A. G. Phadke, "A novel adaptive current protection scheme for distribution systems with distributed generation," *International Journal of Electrical & Power Energy System*, vol. 43, no. 1, pp. 1460–1466, Dec. 2012, doi: 10.1016/j.ijepes.2012.07.024.

[30] B. Hussain, S. M. Sharkh, S. Hussain, and M. A. Abusara, "An adaptive relaying scheme for fuse saving in distribution networks with distributed generation," *IEEE Transactions on Power Delivery*, vol. 28, no. 2, pp. 669–677, Apr. 2013, doi: 10.1109/TPWRD.2012.2224675.

[31] P. H. Shah and B. R. Bhalja, "New adaptive digital relaying scheme to tackle recloser–fuse miscoordination during distributed generation interconnections," *IET Generation, Transmission & Distribution*, vol. 8, no. 4, pp. 682–688, Apr. 2014, doi: 10.1049/iet-gtd.2013.0222.

[32] M. H. Cintuglu, T. Ma, and O. A. Mohammed, "Protection of Autonomous Microgrids Using Agent-Based Distributed Communication," *IEEE Transactions on Power Delivery*, vol. 32, no. 1, pp. 351–360, Feb. 2017, doi: 10.1109/TPWRD.2016.2551368.

[33] H. F. Habib, A. A. S. Mohamed, M. El Hariri, and O. A. Mohammed, "Utilizing supercapacitors for resiliency enhancements and adaptive microgrid protection against communication failures," *Electrical Power Systems Research*, vol. 145, pp. 223–233, Apr. 2017, doi: 10.1016/j.epsr.2016.12.027.

[34] W. Rebizant, J. Szafran, and A. Wiszniewski, "Hardware and Functional Development of Protection Devices and Systems," *Digital Signal Processing in Power System Protection and Control*, pp. 13–27, 2011, [Online]. Available: https://link.springer.com/chapter/10.1007%2F978-0-85729-802-7_3

[35] S. B. A. Bukhari, R. Haider, M. Saeed Uz Zaman, Y. S. Oh, G. J. Cho, and C. H. Kim, "An interval type-2 fuzzy logic based strategy for microgrid protection," *International Journal of Electrical & Power Energy System*, vol. 98, pp. 209–218, Jun. 2018, doi: 10.1016/j.ijepes.2017.11.045.

[36] D. S. Kumar, D. Srinivasan, and T. Reindl, "A Fast and Scalable Protection Scheme for Distribution Networks with Distributed Generation," *IEEE Transactions on Power Delivery.*, vol. 31, no. 1, pp. 67–75, Feb. 2016, doi: 10.1109/TPWRD.2015.2464107.

[37] S. Kar, S. R. Samantaray, and M. D. Zadeh, "Data-Mining Model Based Intelligent Differential Microgrid Protection Scheme," *IEEE Systems Journal*, vol. 11, no. 2, pp. 1161–1169, Jun. 2017, doi: 10.1109/JSYST.2014.2380432.

[38] M. Manohar, E. Koley, and S. Ghosh, "Reliable protection scheme for PV integrated microgrid using an ensemble classifier

approach with real-time validation," *IET Science, Measurement & Technology*, vol. 12, no. 2, pp. 200–208, Mar. 2018, doi: 10.1049/iet-smt.2017.0270.
[39] S. A. Saleh, R. Ahshan, M. S. Abu-Khaizaran, B. Alsayid, and M. A. Rahman, "Implementing and testing d-q WPT-based digital protection for microgrid systems," *IEEE Transactions on Industry Applications*, vol. 50, no. 3, pp. 2173–2185, Jun. 2014, doi: 10.1109/TIA.2013.2290814.
[40] S. A. Saleh, "Signature-coordinated digital multirelay protection for microgrid systems," *IEEE Transactions on Power Electronics*, vol. 29, no. 9, pp. 4614–4623, Sep. 2014, doi: 10.1109/TPEL.2013.2285978.
[41] J. J. Q. Yu, Y. Hou, A. Y. S. Lam, and V. O. K. Li, "Intelligent Fault Detection Scheme for Microgrids with Wavelet-based Deep Neural Networks," *IEEE Transactions on Smart Grid*, vol. 10, no. 2, pp. 1694 - 1703, Nov. 2017, doi: 10.1109/TSG.2017.2776310.
[42] M. A. Farhan and S. S. K, "Mathematical morphology-based islanding detection for distributed generation," *IET Generation, Transmission & Distribution*, vol. 11, no. 14, pp. 3449–3457, Sep. 2017, doi: 10.1049/iet-gtd.2016.1163.
[43] X. Li, A. Dysko, and G. M. Burt, "Traveling wave-based protection scheme for inverter-dominated microgrid using mathematical morphology," *IEEE Transactions on Smart Grid*, vol. 5, no. 5, pp. 2211–2218, Sep. 2014, doi: 10.1109/TSG.2014.2320365.
[44] A. Gururani, S. R. Mohanty, and J. C. Mohanta, "Microgrid protection using Hilbert–Huang transform based-differential scheme," *IET Generation, Transmission & Distribution*, vol. 10, no. 15, pp. 3707–3716, Nov. 2016, doi: 10.1049/iet-gtd.2015.1563.
[45] M. Mishra and P. K. Rout, "Detection and classification of micro-grid faults based on HHT and machine learning techniques," *IET Generation, Transmission & Distribution*, vol. 12, no. 2, pp. 388–397, Jan. 2018, doi: 10.1049/iet-gtd.2017.0502.
[46] S. B. A. Bukhari, M. S. U. Zaman, R. Haider, Y. S. Oh, and C. H. Kim, "A protection scheme for microgrid with multiple distributed generations using superimposed reactive energy," *Intational Journal Electrical Power Energy Systems*, vol. 92, pp. 156–166, Nov. 2017, doi: 10.1016/j.ijepes.2017.05.003.
[47] S. Kar and S. R. Samantaray, "Time-frequency transform-based differential scheme for microgrid protection," *IET Generation, Transmission & Distribution*, vol. 8, no. 2, pp. 310–320, 2014, doi: 10.1049/iet-gtd.2013.0180.
[48] S. Kar and S. R. Samantaray, "Combined S-transform and data-mining based intelligent micro-grid protection scheme," *2014 Students Conference on Engineering and Systems*, pp. 1–5, May 2014, doi: 10.1109/SCES.2014.6880053.
[49] S. F. Zarei and M. Parniani, "A Comprehensive Digital Protection Scheme for Low-Voltage Microgrids with Inverter-Based and Conventional Distributed Generations," *IEEE Transactions on Power Delivery*, vol. 32, no. 1, pp. 441–452, 2017, doi: 10.1109/TPWRD.2016.2566264.
[50] E. Casagrande, W. L. Woon, H. H. Zeineldin, and D. Svetinovic, "A differential sequence component protection scheme for microgrids with inverter-based distributed generators," *IEEE Transactions on Smart Grid*, vol. 5, no. 1, pp. 29–37, Jan 2014, doi: 10.1109/TSG.2013.2251017.
[51] A. Pathirana, A. Rajapakse, and N. Perera, "Development of a hybrid protection scheme for active distribution systems using polarities of current transients," *Electric Power System Research*, vol. 152, pp. 377–389, Nov. 2017, doi: 10.1016/j.epsr.2017.07.022.
[52] S. Kar, "A comprehensive protection scheme for micro-grid using fuzzy rule base approach," *Energy Systems*, vol. 8, no. 3, pp. 449–464, 2017, doi: 10.1007/s12667-016-0204-x.
[53] K. Lai, M. Illindala, and M. Haj-ahmed, "Comprehensive Protection Strategy for an Islanded Microgrid Using Intelligent Relays," *2015 IEEE Industry Applications Society Annual Meeting*, vol. 53, no. 1, pp. 1–11, Oct. 2015, doi: 10.1109/IAS.2015.7356952.
[54] K. O. Oureilidis and C. S. Demoulias, "A Fault Clearing Method in Converter-Dominated Microgrids with Conventional Protection Means," *IEEE Transactions on Power Electronics.*, vol. 31, no. 6, pp. 4628–4640, Jun. 2016, doi: 10.1109/TPEL.2015.2476702.
[55] A. H. A. Bakar, B. Ooi, P. Govindasamy, C. Tan, H. A. Illias, and H. Mokhlis, "Directional overcurrent and earth-fault protections for a biomass microgrid system in Malaysia," *Intational Journal Electrical Power Energy Systems*, vol. 55, pp. 581–591, Feb. 2014, doi: 10.1016/j.ijepes.2013.10.004.
[56] A. Hooshyar and R. Iravani, "A New Directional Element for Microgrid Protection," *IEEE Transactions on Smart Grid*, vol. 9, no. 6, pp. 6862–6876, Nov. 2018, doi: 10.1109/TSG.2017.2727400.
[57] M. A. Zamani, A. Yazdani, and T. S. Sidhu, "Investigations Into the Control and Protection of an Existing Distribution Network to Operate as a Microgrid: A Case Study," *IET Conference on Renewable Power Generation (RPG 2011)*, pp. 42–42, 2011, doi: 10.1049/cp.2011.0115.
[58] A. H. Etemadi and R. Iravani, "Overcurrent and overload protection of directly voltage-controlled distributed resources in a microgrid," *IEEE Transactions on Industrial Electronics.*, vol. 60, no. 12, pp. 5629–5638, Dec. 2013, doi: 10.1109/TIE.2012.2229680.
[59] D. M. Bui, K.-Y. Lien, S.-L. Chen, Y.-C. Lu, C.-M. Chan, and Y.-R. Chang, "Investigate dynamic and transient characteristics of microgrid operation and develop a fast-scalable-adaptable algorithm for fault protection system," *Electrical Power System Research*, vol. 120, pp. 214–233, Mar. 2015, doi: 10.1016/j.epsr.2014.04.003.
[60] Z. Akhtar and M. A. Saqib, "Microgrids formed by renewable energy integration into power grids pose electrical protection challenges," *Renewable Energy*, vol. 99, pp. 148–157, Dec. 2016, doi: 10.1016/j.renene.2016.06.053.
[61] S. Mirsaeidi, D. M. Said, M. W. Mustafa, M. H. Habibuddin, and K. Ghaffari, "A Protection Strategy for Micro-Grids Based on Positive-Sequence Impedance," *Distributed Generation & Alternative Energy Journal*, vol. 31, no. 3, pp. 7–32, Jun. 2016, doi: 10.1080/21563306.2016.11744002.
[62] A. Hussain, M. Aslam, and S. M. Arif, "N-version programming-based protection scheme for microgrids: A multi-agent system based approach," *Sustainable Energy, Grids Networks*, vol. 6, pp. 35–45, Jun. 2016, doi: 10.1016/j.segan.2016.02.001.
[63] X. Lin, R. Zhang, N. Tong, X. Li, M. Li, and D. Yang, "Regional protection scheme designed for low-voltage micro-grids," *International Journal Electrical Power & Energy System*, vol. 64, pp. 526–535, Jun. 2015, doi: 10.1016/j.ijepes.2014.07.050.
[64] A. Khademlahashy, L. Li, J. Every, and J. Zhu, "A review on protection issues in micro-grids embedded with distribution generations," *2017 12th IEEE Conference on Industrial Electronics and Applications (ICIEA)*, vol. 2018-Febru, pp. 913–918, 2018, doi: 10.1109/ICIEA.2017.8282969.
[65] W. K. A. Najy, H. H. Zeineldin, and W. L. Woon, "Optimal protection coordination for microgrids with grid-connected and islanded capability," *IEEE Transactions on Industrial Electronics*, vol. 60, no. 4, pp. 1668–1677, Apr. 2013, doi: 10.1109/TIE.2012.2192893.
[66] L. Huchel, H. H. Zeineldin, and E. F. El-Saadany, "Protection Coordination Index Enhancement Considering Multiple DG Locations Using FCL," *IEEE Transactions on Power Delivery*, vol. 32, no. 1, pp. 344–350, Feb. 2017, doi: 10.1109/TPWRD.2016.2533565.
[67] A. Elmitwally, E. Gouda, and S. Eladawy, "Optimal allocation of fault current limiters for sustaining overcurrent relays

coordination in a power system with distributed generation," *Alexandria Engineering Journal*, vol. 54, no. 4, pp. 1077–1089, 2015, doi: 10.1016/j.aej.2015.06.009.

[68] T. Ghanbari and E. Farjah, "Unidirectional fault current limiter: An efficient interface between the microgrid and main network," *IEEE Transactions on Power Systems*, vol. 28, no. 2, pp. 1591–1598, 2013, doi: 10.1109/TPWRS.2012.2212728.

[69] K. Wheeler, M. Elsamahy, and S. Faried, "Use of superconducting fault current limiters for mitigation of distributed generation influences in radial distribution network fuse–recloser protection systems," *IET Generation, Transmission and Distribution*, vol. 11, no. 7, pp. 1605–1612, Jan. 2017, doi: 10.1049/iet-gtd.2015.1156.

[70] H. He *et al.*, "Application of a SFCL for Fault Ride-Through Capability Enhancement of DG in a Microgrid System and Relay Protection Coordination," *IEEE Transactions on Applied Superconductivity*, vol. 26, no. 7, pp. 1–8, Oct. 2016, doi: 10.1109/TASC.2016.2599898.

[71] M. Ebrahimpour, B. Vahidi, and S. H. Hosseinian, "A Hybrid Superconducting Fault Current Controller for DG Networks and Microgrids," *IEEE Transactions on Applied Superconductivity*, vol. 23, no. 5, pp. 1–6, Oct. 2013, doi: 10.1109/TASC.2013.2267776.

BIOGRAPHIES OF AUTHORS

Zaid Alhadrawi received a Bachelor of Electrical Engineering in 2006 at Kufa university, Iraq and Master of scince in Electrical Power Engineering at University of Technology, Baghdad. He is currently working on his Ph.D. degree at at Universiti Tun Hussein Onn Malaysia, Malaysia. He can be contacted at email: zaidt.alhaddrawi@uokufa.edu.iq

Ts. Dr. Mohd Noor Abdullah received his B.Eng. (Hons) in Electrical Engineering and M. Eng. in Electrical Engineering (Power System) from Universiti Teknologi Malaysia (UTM) in 2008 and 2010 respectively. He also received a Ph. D degree in Electrical Engineering from University of Malaya (UM) in 2014. Currently, he is a Senior Lecturer in the Department of Electrical Engineering and principal researcher of Green and Sustainable Energy (GSEnergy) Focus Group, Faculty of Electrical and Electronic Engineering (FKEE), Universiti Tun Hussein Onn Malaysia (UTHM). He is the author and co-author of more than 60 publications in international journals and proceedings in the area power and energy system. He is a senior member of IEEE. He received the Professional Technologist title from Malaysia Board of Technologists Malaysia. He also a qualified person of SEDA Malaysia Grid Connected Photovoltaic System design. His research interests include energy management and efficiency, power dispatch, distributed generation, renewable energy and meta-heuristic optimization techniques. He can be contacted at email: mnoor@uthm.edu.my

Hazlie Mokhlis received a Bachelor of Engineering (Electrical) in 1999 and Master of Science from Universiti Malaya, Malaysia, in 2002 and a Ph.D. from the University of Manchester, United Kingdom, in 2009. He is the author and co-author of more than 300 publications in international journals and proceedings in the area power and energy ssytem. Up to now, he had successfully supervised 33 PhD and more than 60 Master Students. Currently, he is a professor with the Department of Electrical Engineering and the Head of Power and Energy System Research Group, Universiti Malaya. He is chairman of IEEE Power Energy Society, Malaysia Chapter and Associate Editor for IEEE Access journal and many other journals. His research is focusing on improving the efficiency and resiliency of power system operation at distribution system. Prof. Mokhlis is senior member of IEEE, Chartered Engineer United Kingdom and a Professional Engineer Malaysia. He can be contacted at email: hazli@um.edu.my