A Research Survey on Microgrid Faults and Protection Approaches

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Abstract. The conventional electrical system, production of power is happened in several places also power transmitted into the grid and finally distribution takes place to the individual customers. In conventional powergrid suffers high capital cost, finite reliability, rising greenhouse gases emissions and growing power losses in the transmission line. The power company is choose an interconnecting diverse nonconventional form small generations close to user places, based on their demand also giving smart lever to the power grid. An extensive result, power generation from microgrid is recommended per scientists it could supplies secure, standard and effective supply of source to individuals. Microgrid integration is already available power delivery network forms more intricate to the radial power distribution network. It further lead to magnitude of fault current is vary aggressively based on operation methods (isolated or grid integrated), source, status, also total distributed production of power. In existing protecting control strategies are modelled in radial energy circulation and centralized production of power, it creates available protecting approach is fall in the microgrid. So, effort is carried out to re-examine the fundamental conceptions also importance, problems experienced by microgrid as theme of diverse protection approaches.

Keywords: Microgrid faults, protection, power system, Fault management

1. Introduction

Present days, the power demand is persistently increasing. The different power generation plants were established to compensate the growing demand of power. Yet, conventional power production has plenty of limitations like emanation of flue gases, minimum performance, more transmission power losses, increasing building & material cost, large commissioning interval also decreased reliableness [1]. Therefore, research scientists idea of integrating various mini-scale generation named as Distributed Generation like diesel plants, photovoltaic generators, blow turbines, mini turbine, mini biomass energy generation, CHP generation [2], close to the LV part to attain necessary demand of power and developing a novel idea called as micro powergrid.

It consists in various energy sources combination of energy storage device, it work in a one regulated unit to attain limited demands of power. According to the power provider, it is a regulated unit of electrical network as retaliate to the electrical systems. According to the user point of view,
microgrid is a network it is specifically modelled for to give secure, effective, stable power supply with the support of localized mini supply controller, network optimizer, disperse protective control system [3].

Energy production through micro power grid consists of Alternating (AC) or Direct Current (DC) supplies, based on distributed micro power resources are connected. In alternating current, the produced voltage was converted into direct current with the support of voltage source converter. Direct current is simultaneously interconnected into electrical powergrid via Voltage Source Converter (VSC) regulated by power electronic controlled approach. The support of Pulse-width modulation technique phase angle and power of the converter will be regulated. The output power of the converter is integrate to the power system through the help of Point of Common Coupling (PCC). The reactance provided through inductive coil to regulate the voltage and phase difference of the converter. The power and phase difference of the PCC determines real power also the imaginary flow of power to the power grid through distributed energy source.

The traditional structure of electrical system, additional loads are abruptly combined initial energy balance compensated by inertia of the system. However inertia was minimum for small sources. It is necessarily compensated through the support of effective energy storage systems. Islanded mode and Grid integrated [4] both are important possible modes of action of microgrid. In grid integrated system, microgrid gets energy from suppliers also distributed energy source. During grid integrated system, main part of active power needed to the load was reached through interconnection of DGs to microgrid also balancing remaining part. The difference in the demand in the active power was fulfill in the grid [3, 5]. In isolated mode, power balance was maintained by the load/generation shedding. The crucial loads to get secure energy in every interval and load shedding were done in the extra loads [3, 6].

Protection scheme perform an essential part in a secure electrical system. Eventual aim beyond in microgrid to deliver secure power to all users. Therefore the fault in the main power grid, microgrid should get far away from other places [7, 8] and fault inner side of microgrid, separate the minimal portion of faulty section. Existing protective control strategy formed in radial network system. The large short circuit current is not act dependable in a microgrid [9] due to below causes.

- Two directional energy movements of power delivery systems
- Changing attributes in distributed energy resources
- Fault current barrier at isolated condition
- Tropological variations of the system because of seasonal behaviour of distributed energy generation
- Change in the amplitude of short circuit current depend on operation modes
- Category of distributed generation used (direct connection or DG inverter connection)
- Total number of distributed generation sources was connected.

So, the appropriate protective control strategy was strictly crucial in microgrid for assure safety performance in grid integrated also isolated connection. Many pilot projects of microgrid were strongly established at several grown nations.

The necessity for control of microgrid also various control schemes are explored at part 2. Microgrid Faults and available AC Protection was described and tabulated in section 3. A diverse problem encountered in protection of microgrid was conferred in part 4. Feasible protective control approaches recommended to microgrid was explained in part 5. Part 6 gives the discussion with conclusion accordingly.
2. Controlling Strategies of Microgrid

Several parameters should be regulated in the microgrid such as frequency, supply voltage, real and complex power should commonly based on various modes of operation. In grid integrated control, power grid sustains supply frequency and voltage of the microgrid. Therefore, primary duties in controller of microgrid are stabilize real power also complex power of the network. An isolated method control of operation, inclusion to power balance of real and imaginary, the controller unit of microgrid must assure the limits of voltage and frequency.

Equilibrium of Power was controlled through Auxiliary Controller (AC) unit only or in the support of various initial set points specified through main controller via contact instrument. In the support of regulated or deregulated supervisory methods those control approaches was executed. It comprises (i) Main Controller (MC) (ii) Local Controller combined (iii) Market Operators (MO). Local Controller unit is answerable for sustain secure supply for buyers and take care of production concern of micro- grid. In basis of scientific also economic features set points of LC unit are given through MCC in the event of regulated method of control. Wherever more than one controller existing at the places grid operators is utilized. The charged for the market operations in every distinct location.

Mechanism for Centralized control method

In centralized method, MCC upgrades new details in each predetermined period of interval as deference to

- Distributed Generation-level (ON/OFF), type, total generation.
- Power–demand
- System variables like voltage, current in every relay position depend on control needs
- Point of common coupling-operation mechanism (integrated to grid/isolated control form

Main controller consists of following main modules such as Power Control Module and Protective control Module. Power Control Module is supervising position points of real power, reactive power, supply frequency and voltage to every local controller via transmission system basis on IEC Protocol 60850 standards. The functions of grid integrated mode of central controller is to

- Supervise the parameters of microgrid
• Planning the cost-effective power production of real and imaginary power management in distributed generation as well as load side control
• Assure coordinated functioning of the grid and utility system

The operations in main controller at isolation method are Provide operational commands in (a) interconnected inverter in main distributed generation also control of supply frequency and output voltage (b) interconnection of inverter for remaining systems as well as active and imaginary power equilibrium in the microgrid. Give directions to local controllers for undertake shedding of load depend on output criteria, reserving the microgrid power. Modulation approach look after protection control strategy in event of malfunction and short circuit occurs in micro grid. As common, the centric protective control strategy employs compatible control techniques in microgrid protection to include variations in fault current by cause of the progressive variations in grid structure. In execution of entire centric microgrid control needs expansive transmission among main controller and supervision units is particularly improbable in vast geo-graphic locations. The entire developed control mechanism to fall in a little fault in the communication system.

Mechanism for Decentralized Control

In inaccessible places, anywhere an interval among the distributed generation is extensive; execution of centric control requires additional intercommunication connection causes high rate. This similar instance, deregulated control of microgrid may be performed. Deregulated system was chosen in microgrid having many numbers of distributed generations was controlled through independent vendors.

In deregulated control, high prominence was specified to local controller for maximum liberty of distributed generations and loads. Analogous to centric mechanism, decentralized system liberty was performed through a sequence in order it comprises distributive system operator, microgrid main controller also local controller. Primary purpose of Local controller was
• Generation rate was increased to meet out power demand
• Give greatest feasible dissemination to power delivery systems
• Enhances in microgrid operation. In every distributed generation was separately regulated in energy distribution along with control of inverter.

3. Microgrid Faults and available AC Protection

Faults in microgrid are classified into generator side fault, converter fault, several sensor faults, load fault, and fault begins by cyber-attack [18]. In microgrid, one pole to ground, double pole and double pole to ground fault appears at DC load part [19]. Traditional short circuit fault such as one phase to ground, line to line, line to line to ground, three line faults appears on AC side and converter faults are also feasible in the AC side microgrid. The feasibility of DC line faults is less than AC transmission line fault, as the distributed generator is near to load center. The AC side faults may be identified by traditional diagnosis and islanding approaches. In DC microgrid, if fault happens on DER side or load side then it is mandatory to first examine whether network is in grid-integrated mode or isolated mode. When system is in autonomous mode then threshold rate of fault current is minimum, as RES not able to supply maximum fault current when alternator generally supply.

From the above discussions, micro grid faults are categorized in to fifteen types. In this section briefly explained the various types of micro grid faults, Causes, Effects and its diagnosis methods.
| S. No. | Fault type                     | Causes of faults                                                | Effects of faults                                      | Faults diagnosis methods                                      |
|-------|--------------------------------|----------------------------------------------------------------|-------------------------------------------------------|--------------------------------------------------------------|
| 1.    | source side faults (in solar, wind etc.,) | 1) intermittent variation of input  
2) enormous dc-link voltage and ac currents;  
3) loss of synchronization in grid voltage | Discontinuity of power flow occurs and the resistance at that fault point becomes zero. | Ensure the reliability of power conditioning device |
| 2.    | converter faults (inverter and converter) | 1. defect due to malfunctions of valves and controllers  
2. Commutation default  
3. Short circuits fault | (i) Fire return  
(ii) Fire trench  
(iii) Misfire  
(iv) Arc extinction | Regulate the rectifier and inverter station the firing angle and minimizes harmful effects. |
| 3.    | load side faults                | Abrupt or continual load variations, overvoltage, uncompensated issues. | Its create power quality problems like voltage sags/swells, voltage flickers, harmonics etc. | To interconnect custom power compensating devices like DSTATCOM, DVR and UPQC etc. |
| 4.    | cable faults                    | Some of the major causes for cable faults are:  
✓ Deterioration  
✓ Wrong selection  
✓ Electrical puncture  
✓ Heating of cable  
✓ Fire and lightning surges  
✓ Mechanical failures  
✓ Corrosion of sheath  
✓ Moisture in the insulation. | Cable faults are leads to effect of resistance and breakdown voltage. It persists, which may destroy the entire cable. | Appropriate design of the cable, cable Earthing methods, cable bonding and power network earthing systems, Installing an earth fault current limiting protection device, such as a neutral earthing resistor/reactor or Peterson Coil, |
| 5.    | data communication faults       | data communication faults occurs due to misconfiguration is the cause of as many as 80% of unplanned outages like  
✓ Hardware failures  
✓ Power failures  
✓ Human error  
✓ Old equipment  
✓ Incompatible changes  
✓ Security breaches | Improper communication and mismatching of parameters like text, programs, images, audio, and telemetry etc. | Monitor and use the various advanced high performance communication networks like wide-area wireless data systems, satellite systems and Mobile Ad Hoc Networks etc. |
| 6.    | cyber security                  | Many causes of cyber security attacks are  
✓ By using own software tools individuals can initiate the attack,  
✓ Criminal organizations running with more enterprise with many employees creating the attacks,  
✓ Terrorists,  
✓ Industrial spies etc. | Theft of valuable, sensitive data, Hacking etc. | maintain software up-to-date, install anti-virus protection software, Implement multi-factor authentication, secure system infrastructure, backup the critical data, provides the training to workers to face the cyber-attacks. |
|   | Internet of things (IoT) protocol failure | Expired software and hardware, Employ powerless credentials, Difficult to identify if a device is damaged, Predicting and preventing attacks, Data protection and security challenges. | Effect of system architecture, security protocols, energy efficiency, and quality of service can be affected by IoT protocol failure. | Use the priority-based energy-efficient routing method |
|---|------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-----------------------------------------------|
|   | Smart meter faults                       | smart meter display is not updating                                                              | Improper measurement leads to high tariff                                                      | Energy savings and consumption reduction as a result of smart use and the optimal. |
|   | One Phase-to-ground (LG Fault)           | Unpredictable or incidental contacts between the single conductor to the ground. Failure of insulation also leads to LG fault. | Create minimum impedance path and maximum current flows to the ground. It persists the loss of output voltage permanently. | Install the earth fault protection devices and fault current regulating devices. |
|   | Phase-to-phase (LL Fault)                | Interconnection between two conductors with unequal potential differences.                        | Create minimum impedance path and creates reverse current flow in the faulted section. It leads to results in fire hazard. | Install the earth fault protection devices, blocking diodes to avoid the reverse current flow and Install fault current regulating devices. |
|   | Two phases-to-ground (LLG Fault)         | Interconnection between two conductors to ground with unequal potential differences.             | Create minimum impedance path between two conductors to ground and creates reverse current flow in the faulted section. It leads to results in fire hazard. | Install the earth fault protection devices, blocking diodes to avoid the reverse current flow and Install fault current regulating devices. |
|   | Three phases (LLL Fault)                 | Interconnection between three conductors with unequal potential differences.                      | Create minimum impedance path between the three conductors and creates reverse current flow in the faulted section. It leads to results in fire hazard. | Install the earth fault protection devices, blocking diodes to avoid the reverse current flow and Install fault current regulating devices. |
|   | Three phases-to-ground fault (LLLG Fault)| Interconnection between three current carrying conductors and ground with different potential variations. | Create minimum impedance path between three conductors to ground and creates reverse current flow in the faulted section. It leads to results in fire hazard. | Install the earth fault protection devices, blocking diodes to avoid the reverse current flow and Install fault current regulating devices like ELCB. |
14 Open circuit fault

The most common causes of open circuit fault include disconnection of overhead lines, cables, loss of one or more conductors of circuit breaker and damage of fuse. It is also called as series faults.

Due to open circuit faults discontinuous path from and back to the source of EMF. It leads to change of its resistance to an extremely high value will cause current to drop.

Check-up affected portion potential on wire 1 at the bottom of the control fuse and at the top of the neutral link.

15 Transformer failure

The main reasons that cause this fault in the transformer are the poor maintenance, corrosion, manufacturing defect, improper adjustment, mechanical and vibration movement within the transformer.

Leads to increases the risk of fire and explosions.

Preventative maintenance is required for this issue should include routine oil filtration.

4. Microgrid protection systems Challenges

To assure secure, reliable functioning of electric grid system appropriate protection scheme including greater selectiveness, quick functioning, uniformity, adaptability, and diverse set possibility also minimum rate was selected.

In reviewed previously, existing protective methods developed in radial outflow along large short circuit current for power delivery systems is not functioning constantly for microgrid due to two directional energy systems, aggressive behaviours of distributed generations, seasonal variations also difference in short circuit fault current. Primary issues occurred of microgrid protective scheme are [15]

- Dynamics variation in magnitude of short circuit current
- Failure of supply
- Redundant separation (deficiency of selectiveness)
- Protection glaring

Protection of Microgrid

An appropriate protection strategy of the microgrid was developed, in order to avoid in every fault, a minimal part of the network was segregated, not attacking remaining network. It was achieved through composition in a primary and secondary protection instruments.

The main protection instrument was managing in every short circuit limited zone. If, the main protection instrument falls in perform, secondary instrument acquires this function. In traditional structure is radial network and protective approach was developed along fuses and protective relay was easier. The presented introduction of distributed generations in existent network forms electrical system structure further complex. Furthermore short circuit current is incalculable, it was varies in working modes, class of DG and generation amount. Therefore, developing in effective protective approach to deal with over mentioned problems is a disputing job. The Thevenin's Equivalent Diagram for microgrid fault system is shown in figure 2. Diverse protective strategy discussed was tabulated (figure 3) and equivalent was examined.

![Figure 2 Thevenin's Equivalent Diagram](image-url)
Microgrid Fault Management: Stages and Techniques

The proper protection scheme requires handling any fault condition in a system, to follow a sequence such as (i) fault diagnosis (ii) fault islanding (iii) fault restoration of the circuit. Figure 4, illustrates the available and recent techniques for fault management. To clear understanding the fault protection features of the microgrid, let us know a few relevant terms:

**Effective Protection:** It is the procedure of recognizing the fault location and then segregating of the minor part of the network when fault take place.

**Fault tolerance:** It is the capability of the network, up to which level the network withstand the fault in the network.

**System Resiliency:** It is the capacity of system to return back to its normal state of action after any type of disturbances happens in system [14]. To enhance resiliency of the microgrid, fault tolerant ability need to be increased using suitable protection strategy.

**Reliability:** It is the capability of system to distribute power with quality and quantity demanded by customer when maintaining the grid operation even if fault appears. For attaining reliability, faulted section separates from the healthy section and the healthy section is maintaining with uninterrupted power supply [15].

The proposed literature several methods for fault management are discussed. In the latest review papers [16] and [17], have concentrated on fault diagnosis approaches. To cover the entire orbit of fault management, this paper discusses the fault islanding and restoration methods. The describes of diverse types of microgrid, their protection strategy, and causes behind several protection approaches are also briefly explained in the paper. Essential points of various methods are shown in Table format for easier understanding.
5. Fault Detection Techniques

When any network operates within restricting constraint then network is said to be stable condition, but if the basic variable get out of limiting constraints then there may be few fault appear in the system. The initial step close to resilience system is fault identification. There are different ways by which fault location can be identified in AC-DC microgrid such as current magnitude, voltage magnitude, voltage gradient [20] and current gradient [21]. The distinction between AC fault and AC-DC microgrid fault identification is depend on grid interconnection. As the position of grid interconnection varies so the restricting value of current also varies. When alternator is interconnected in network then it has a maximum ability to provide the fault current but when the microgrid function in autonomous condition, ability of system to contribute fault current is very minimum as compared to alternator. So, the limiting magnitude in protection instrument may be varied as per the grid conditions. Fault identification in microgrid may be disregarding of the current supply directions. Tables 2 listing the several approaches for fault identification and few important points related to that. The identification approach works effectively in AC side but for AC-DC grid it requires communication layer to set the current position of the network. On the basis of existence of
5. Communication Layer Protection Network

The communication layer protection network has two methods: adaptive and non-adaptive protection approaches [22].

5.1. AI based Protection Scheme

Artificial Intelligence (AI) based techniques like fuzzy logic system controller-based protection, AI-based differential methods, and Artificial Neural Network-based approach are presented in existing survey. Proposed methods represent signals obtained from phasor measurement unit (PMU) examined through various filters such as Kalman filter techniques, discrete Fourier transform (DFT) [23], etc. The ultimate relaying signal is determined by fuzzy logic, ANN, AI decision tree. ANN has a drawback that it particularly operates for trained system topologies and training should be complex as system again goes more difficult.

Fuzzy logic based approaches regularly supervise the conditions of RES, grid, and value of voltages. The pickup parameters and time setting multiplier (TSM) is evaluated regularly and basis on computation of TSM and pick up values protection instruments investigates and explore the fault. The fuzzy protection strategy is constricted by network topology, where recognizing the network topology is limiting inhibition [23].

![Figure 5: Microgrid fault protection devices](image)

**Table 2: Review on Fault Detection Methods**

| Method            | Key Features                                           | Reference |
|-------------------|--------------------------------------------------------|-----------|
| Fuse              | - Generally employed in AC system for medium and low rating applications  
                  | - Quick response and economic in nature                  | [27]      |
| Over-current Relay| - Comparison of current with stable preset threshold rate  
                  | - Backup protection is required                          | [28][29] |
Directional Protection

- Intelligent Protection Devices (IED) are employed for supervising and control, by using voltage, current direction and magnitude
- High-speed communication and High sensitivity sensors are necessary

Current Differential Protection and Rate of change in current (di/dt)

- Differentiation in between input and output taken into account
- Needed for high bandwidth sensors
- Easy to implement, limit excessive rate of current given by capacitance in faulty environment

Adaptive distance protection

- Impedance value is estimated by applying current and voltage measurement from PMUs
- Earlier to fault, impedance magnitude reduces immediately

AI based Protection

- Threshold magnitude measured using fuzzy logic control
- Various filters are employed to examine measured signals

Harmonic based protection

- Fast Fourier Transform methods is employed
- Performance based on penetration level of RES

Multilayered Protection

- Composition of various protection strategy
- Costly and powerful between all approaches

Travelling wave method and ANN

- Applied for fault identification and localization
- Require more memory and processing time

5.2 Fault Isolation and Restoration

The isolation methods are used to terminate a high fault current flow in the network by isolate the faulted part from the network. As fault identification and localization is done, the next step for maintenance of reliability is fault quarantine, whatever fault is identified that should be separated from remaining of the healthy system. Speed of response and selectivity has significant change on fault islanding. Circuit breaker and fuse is the primary fault protection instruments in AC network. In microgrid network, modular multi-level converter (MMC) approach and fault limiting generating methods are exemplar of emerging breaker-less fault separating devices. Current research is concentrated on breaker less islanding devices primarily utilizing MMC. The approaches for fault separation and few essential parameters is expressed in Tables 3. There are two classifications of protection elements are, without and with breaker. Some advanced fault identification and isolation approaches are signal processing techniques such as shortened-moment fourier transform based methods, wavelet transform methods, ANN optimization algorithm and traveling wave based methods [20], operates on the fault approach in which time differentiation between reflected and incident waves computed [16], [32], [33].

| Devices                        | Approaches | Functions and key features                                                                 | Reference |
|-------------------------------|------------|-------------------------------------------------------------------------------------------|-----------|
| Conventional Circuit Breaker  | Fuse       | • Generally used in both DC and AC                                                        | [27]      |
|                               | DCCB       | • Resonant method is employed to forcefully make zero crossing                             | [34], 35, 36 |
|                               |            | • Surge arrestors are employed to extract more energy at the beginning of isolation        |           |

Table 3 Review on Fault Isolation Devices
### 4. Solid State Circuit Breakers (SSCB)

- **Controlled switch based**
- **Works not depend of current direction due to anti-parallel switches**
- More quantity of current can dissipated
- Capability of Self-triggered interruption
- Single-shot operation

- **SSFCL**
- More quantity of current can dissipated
- Capability of Self-triggered interruption
- Single-shot operation

- **DC/DC Converter based fault Separation**
- **Bidirectional Buck-Boost converter**
- Diagnose the fault not depending on direction of current
- More effective
- Capacitive current control methods is required
- Communication needed for controlling

- **Fault- Tolerant Generation**
- At fault state, supply of fault current is decreased by functioning of converter switches.

- **MMC**
- Used to control more capacitive discharge for high rating networks

- **Interfaced Generators**
- By balancing the field excitation, fault current supply is modified

### 6. Conclusion

Enhancing energy demand can be achieved through adding in additional microgrid distributed generation. In adding of sources at distribution side creates the available protective techniques are inefficient. It causes deficiency in existence techniques also several protective methods proposed in various conditions of microgrid are explored. Adaptive protective approach was effective methods for microgrid protection, so the dynamic variations of distributive structure topology are included for relay setting computation.

### 7. Future Scope

The several faults on microgrid and various techniques to analyze and identify the faults stated in literature are examined in the paper. The necessity for various protection approaches from existing methods is described based on diverse perspective. This literature presents various possible methods of fault identification, fault islanding and restoration of microgrid. There are few advanced methods for fault identification and islanding in which various converter topologies are employed for fault clearing. Few fault-tolerant generations are also indicated which itself can limit the faults. The Adaptive protection approach based on communication and other approaches are also explained in detail to realize their importance and performance. The conception of fault resilient and tolerant system is described and ways to attain the system resiliency is examined.

For modern protection, hardware integration system with communication for protection utilizing evolved protection methods of IED tools is the future directions. If data from various protection methods indicated above are available then results comparison can be executed which leads to explore finest protection approach according to several network topologies. Emerging approaches for hardware implementation is the future work which needs to be described.

### References

[1] Bob Lasseter 2011 Microgrids:Role of distributed generation in reinforcing the critical electric power infrastructure *Institute of Electrical and Electronics Engineers WM Panel* vol.23 Issue No.2 pp.547-557.

[2] Kroposki B et al. 2018 Making microgrids work *Power Energy Mag. IEEE* vol.6 Issue No.1 pp.50–63.
[3] Lasseter RH 2012 Microgrid. In: Proceedings of the IEEE power and energy society winter meeting New York vol.1, pp.315–18.

[4] Mahesh Illindala, GiriVenkataramanan 2012 Microgrid and sensitive loads, In: Power engineering society winter meeting Institute of Electrical and Electronics Engineers vol.1 Issue No.1 pp. 27–31

[5] Xinyao Dysko Adam. M.Burt 2015 Travelling wave based protection scheme for inverter dominated microgrid using mathematical morphology IEEE transaction on smart grid vol.5 Issue No.5 pp.15–28.

[6] A. Stonier, S. Murugesan, R. Samikannu, S. K. Venkatachary, S. Senthil Kumar and P. Arumugam, "Power Quality Improvement in Solar Fed Cascaded Multilevel Inverter With Output Voltage Regulation Techniques," in IEEE Access, vol. 8, pp. 178360-178371, 2020, doi: 10.1109/ACCESS.2020.3027784

[7] S.A. Alexander, T. Manigandan, Design and Development of Digital Control Strategy for Solar Photovoltaic Inverter to Improve Power Quality, CEAI, 16, 4, pp. 20–29, 2014.

[8] Albert Alexander S., Manigandan. T 2014 Power Quality Improvement in Solar Photovoltaic System to Reduce Harmonic Distortions using Intelligent Techniques Journal of Renewable and Sustainable Energy Vol.6 Issue.4 pp. 043127 (1)-(19) ISSN 1941-7012.

[9] Alexander SA, Thathan M. Reduction of voltage harmonics in solar photovoltaic fed inverter of single phase stand alone power system. J Solar Energy Eng. 2014;136(4):044501.

[10] Albert, A.S.; and Manigandan, T. (2014). Digital control strategy for solar photovoltaic fed inverter to improve power quality. Journal of Renewable and Sustainable Energy, 6(1), 013128

[11] Srivastava Anurag K, Zamora Ramon 2020 Controls for microgrids with storage:review, challenges, and research needs. Renew Sustain Energy Rev. vol.1 Issue No.1 pp. 2019– 28.

[12] Vanthournout K, De Brabandere K, Belmans R., Driesen J 2017 Control of microgrids, In: Proceedings of IEEE power engineering society general meeting.

[13] Etemadi AHP alma-Behnke, Olivares DEM ehrizi- SaniA et al. 2016 Trends in microgrid control. In: IEEE transaction on smart grid vol.5(4). pp.1815–29.

[14] Cox.W and Considine.T 2014 Grid fault recovery and resilience:Applying Structured Energy and microgrids IEEE PES Innovative Smart Grid Technologies (ISGT 2014) Washington DC pp.1-5.

[15] Mili.L, Mehrmanesh.L, Arghandeh.R, and Meier.A 2016 On the definition of cyber-physical resilience in power systems Renewable and Sustainable Energy Reviews vol.58 issue.5 pp.1060-1069.

[16] Tzelepis.D, Dong.X, Shi.S, and Mirsaedi.I 2017 Challenges, advances and future directions in protection of hybrid AC/DC microgrids IET Renewable Power Generation vol.11 issue no.12 pp. 1495-1502.

[17] Soltani.M, Hajizadeh.A, and Bayati.N 2018 Protection in DC Microgrids:A comparative review IET Smart Grid vol.1 issue no.3 pp. 66-75.

[18] Islam S.N, Roy T.K, Mahmoud M.A, Haque M.E, and Saha.S 2018 Sensor fault and cyber-attack resilient operation of DC microgrids International Journal of Electrical Power & Energy Systems vol. 89 issue no.4 pp. 96-105.

[19] Satarkar M.F.A.R and Patil.G 2014 Autonomous protection of low voltage DC microgrid International Conference on Power, Automation and Communication (INPAC), Amravati pp. 33-36.

[20] Klosinski.C et al., 2018 Modular protection system for fault detection and selective fault clearing in DC microgrids Journal of Engineering issue no.15, pp.1821-1835.

[21] Kanakasabapathy.P and Vishnupriya.S 2016 Fault Ride Through for a DC ring bus microgrid, International Conference Energy Efficient Technologies for Sustainability (ICEETS), Nagercoil, pp. 21-26.
[22] Zengping.W, Jinlong.L, and Jing.M 2017 An adaptive distance protection scheme for distribution system with distributed generation, 5th International Conference on Critical Infrastructure (CRIS), Beijing, pp.11-16.

[23] Liu.C, Guerrero J.M, Vásquez J.C, and Lin.H 2015 Adaptive distance protection for microgrids, IECON 2015-41st Annual Conference of the IEEE Industrial Electronics Society, Yokohama, pp.745-760.

[24] Ooi B.L. and Tang 2017 Locating and Isolating DC Faults in Multi-Terminal DC Systems, IEEE Trans. Power Delivery vol.22 issue no.3 pp.1977-1984.

[25] IEEE Application Guide for Low-Voltage AC Power Circuit Breakers Applied with Separately-Mounted Current-Limiting Fuses 2018 IEEE Std C37.27 pp.C1-21.

[26] Hatziargyriou.N 2018 The Microgrids Concept, IEEE Microgrids: Architectures and Control

[27] Sahoo A.K. 2018 Protection of microgrid through coordinated directional over-current relays, IEEE Global Humanitarian Technology Conference-South Asia Satellite (GHTC-SAS), Trivandrum, pp. 149-154.

[28] Emhemed A.A.S., Fong.K, Fletcher.S, and Burt G.M. 2018 Validation of Fast and Selective Protection Scheme for an LVDC Distribution Network, IEEE Trans. Power Delivery vol.32, issue no. 3, pp.279-294.

[29] Mohan.M and Kanakasabapathy.P 2015 Digital protection scheme for microgrids using wavelet transform, IEEE International Conference on Electron Devices and Solid-State Circuits (EDSSC), Singapore, pp.768-777.

[30] Zayegh.A, Ozansoy.C, and Ustun T.S. 2012 Modeling of a Centralized Microgrid Protection System and Distributed Energy Resources According to IEC 61850-7-420 IEEE Trans. Power Systems vol.28 issue no.3 pp.1660-1667.

[31] Zengping.W, Jing.M, and Jinlong.L 2016 An adaptive distance protection scheme for distribution system with distributed generation, 5th International Conference on Critical Infrastructure (CRIS), Beijing, pp.11-18.

[32] Kishore, Dash.P, and Dhar.S 2019 Differential current-based fault protection with adaptive threshold for multiple PV-based DC microgrid IET Renewable Power Generation vol.11 Issue no.6 pp.778-790.

[33] Liu.C, Guerrero J.M, Vásquez J.C, and Lin.H 2015 Adaptive distance protection for microgrids, IECON 2015-41st Annual Conference of the IEEE Industrial Electronics Society, Yokohama, pp. 845-860.

[34] Reindl.T, Srinivasan.D, and Kumar D.S. 2016 A Fast and Scalable Protection Scheme for Distribution Networks With Distributed Generation, IEEE Trans. Power Delivery vol.31 Issue No.1 pp.67-75.

[35] Zhu.Y and Yang.M 2015 Study on adaptive distance protection using multi-agent technology, International Power Engineering Conference, Singapore, vol.2 pp.618-622.

[36] Peng.L., Pei.X, and Chen.Z 2018 Harmonic components based protection strategy for inverter-interfaced AC microgrid, IEEE Energy Conversion Congress and Exposition (ECCE), Milwaukee, WI, pp. 1-6.

[37] Pou.J, Ukil.A, and Satpathi.K 2018 Short-Circuit Fault Management in DC Electric Ship Propulsion System: Protection Requirements, Review of Existing Technologies and Future Research Trends IEEE Trans. Transportation Electrification vol.4 Issue no.1 pp.272-291.

[38] Lee B.W, Khan U.A, Suwarno, Koo J.Y, and Pramudya.I 2017 Modelling and evaluation of low voltage DC circuit breaker for the protection of DC microgrid, International Conference on Condition Monitoring and Diagnosis (CMD), Xi’an, pp.395-405.

[39] Venkataramanan.G and Cuzner R.M. 2018 The Status of DC Micro-Grid Protection, IEEE Industry Applications Society Annual Meeting, Edmonton, pp.11-28.

[40] Dhar.S and Dash P.K. 2019 Adaptive threshold based new active islanding protection scheme for multiple PV based microgrid application, IET Generation, Transmission & Distribution vol.11 issue no.1 pp.218-232.
[41] Almutairy.I 2016 Solid state circuit breaker protection devices for DC microgrid in review, 5th International Conference on Electronic Devices, Systems and Applications (ICEDSA), Ras Al Khaimah, pp.11-23.

[42] Xiaoming.Z, Hua.Y, Fei.L, Jianjun.S, and Wenjun.L 2015 An improved RCD snubber for solid-state circuit breaker protection against bus fault in low-voltage DC microgrid, IEEE 2nd International Future Energy Electronics Conference (IFEEC), Taipei, pp.11-25.

[43] Farjah.E and Ghanbari.T 2017 Development of an Efficient Solid-State Fault Current Limiter for Microgrid, IEEE Trans. Power Delivery vol.27 Issue No.4 pp.1739-1754.

[44] Yao.L, Xu.L, and Zeng.R 2015 An improved RCD snubber for solid-state circuit breaker protection against bus fault in low-voltage DC microgrid, IEEE 2nd International Future Energy Electronics Conference (IFEEC), Taipei, pp.11-25.

[45] Farjah.E and Ghanbari.T 2017 Development of an Efficient Solid-State Fault Current Limiter for Microgrid, IEEE Trans. Power Delivery vol.27 Issue No.4 pp.1739-1754.

[46] Arshad W.M, Lendenmann.H, Chin.R, and Polinder.H 2019 Fault tolerant generator systems for wind turbines, IEEE International Electric Machines and Drives Conference, Miami, FL, pp. 785-791.

[47] Zheng.H, Rodrigues.R, and Cairoli.P 2019 Fault current limiting power converters for protection of DC microgrids, SoutheastCon, Charlotte, NC, pp. 55-67.

[48] Bevrani.H, and Hajimohamadi.N 2016 Load shedding in microgrids, 21st Iranian Conference on Electrical Engineering (ICEE), Mashhad, pp. 43-56.

[49] Dang. and Khoa.T 2018 Load shedding and restoration real-time optimization for DC microgrid power balancing, IEEE International Energy Conference (ENERGYCON), pp.77-86.

[50] Wagner and Leal.C 2014 A control system for battery current sharing in DC microgrids with DC bus voltage restoration, Brazilian Power Electronics Conference (COBEP), pp.56-66.

[51] P. Shanmuga Aravind and S. Albert Alexander, “Harmonic minimization of a solar fed cascaded H Bridge inverter using Artificial Neural Network,” 2013 International Conference on Energy Efficient Technologies for Sustainability, Nagercoil, 2013, pp. 163-167, doi: 10.1109/ICEETS.2013.6533376.

[52] Sampath Kumar Venkatachary, Ravi Samikannu, Srinivasan Murugesan, Narasimha Rao Dasari, Ragupathy Uthandipalayam Subramaniyam, Nov. 2020, Economics and impact of recycling solar waste materials on the environment and health care, “Environmental Technology & Innovation”, Vol.20, no.101130, pp. 1-14.