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Microgrid Control, Storage, and Communication Strategies to Enhance Resiliency for Survival of Critical Load

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ABSTRACT Adequately, as far as the global system is concerned with the variation in the climatic condition, the frequency of disaster is rising, resulting in various damages to the power grid. To cope with the power network problems due to disasters such as grid outages, frequency, and voltage deviation, the network should be incorporated with numerous distributed generations such as solar and wind. During the disaster condition, these distributed fossil generations form Microgrids (MGs) by disconnecting itself from the grid and maintain power flow to the local region. Besides, the negative impacts on the environment, such as carbon emission has reduced by using Renewable Energy Sources (RES). Apart from reducing carbon emission (as in the case of fossil fuel generation plants), RES based microgrid also useful for the resilient distribution system. However, high penetration of distributed generation, for a resilient system that can survive at least its critical loads during extreme disaster conditions, requires robust architecture and communication between the devices of a microgrid. This article presents the latest review of the various classification of microgrid architecture along with the technical characteristics of energy storage devices, various communication channels and discover the gaps to form a bridge between microgrid in normal and abnormal (during a climatic disaster) conditions. In addition, alteration in control techniques for Alternative Current and Direct Current microgrid for robust MGs is presented systematically. Furthermore, the latest developments with sectionalizer placement to provide the steps to achieve near-real-time data and necessary actions required to take during or before the actual disaster are also presented in a systematic manner.

INDEX TERMS Power grids, distributed power generation, energy storage, communication system control, resilience.

LIST OF ABBREVIATIONS & NOMENCLATURE

CAES	Compressed air energy storage
CB	Circuit Breakers
CoAP	Constrained Application Protocol
DER	Distributed energy resources
DG	Distributed generations
DSR	Distribution System Restoration
DR	Distributed Resources
DSR	Distribution system restoration
ESS	Energy storage system
ESU	Energy storage unit
FPI	Fault passage indicator
IED	Intelligent electronic devices
IoT	Internet of Things
IS	Intelligent Switches
LC	Load Controller
MGCC	Microgrid central controller
MG	Microgrid
MNRE	Ministry of New and Renewable Energy
MQTT	Message Queuing Telemetry Transport
PCC	Point of common coupling
PLC	Power line carrier
QoS	Quality of Service
RES	Renewable energy sources
SCADA	Supervisory control and data acquisition
t_d	Delay in propagation
t_s	Duration of transmission

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t_r	Time duration to pass on the incoming message to the receiver's application
t_{max}	Maximum delay time

I. INTRODUCTION

Due to an abrupt change in the climate, the frequency of natural disasters such as cyclones, floods, tornados, hurricanes, and many are likely to arise in the future. To cope with power system failure because of low probability & high impact events, a hybrid power network, i.e., micro-grids are rising as the prominent approach, as it uses the significant available renewable energy resources (RES) such as solar energy and wind power. According to [1], the global power from solar and wind energy would be 613 GW and 793GW respectively by the end of the year 2020, which means proper selection of architecture and robust control mechanism concerning specific locations is a significant challenge for stable operation of the grid.

Microgrid (MG) is evidently an attractive network for robust architecture, but higher penetration leads to negative results on the electrical grid. MG links small transmission and distribution to effectively employ all the specific located distributed generations (DGs) and other devices [2]. These networks are self-empowered systems and can be operated either with the main grid or in the isolated mode (islanding). However, the microgrid master controller (MGCC) is "brain of the microgrid" [1], which decides the modes of operation of the microgrid, i.e., off-grid or on-grid. This small self-sufficient system would allow maximum extraction of renewable power by coordinating control between renewable and the fuel-based generators [3]. Microgrid (MG) is operated in two modes, i.e., grid connected and islanding mode [4]. When the system goes in islanding mode, the network parameters such as voltage, current, and frequency changes, thereby leading to specific problems such as grid outages, frequency variation, and voltage deviation [5]. To overcome these problems, there are some standards defined by system operators that have to be followed. Table 1 shows international standards for islanding mode of the microgrid [6].

TABLE 1. Standards for islanding mode.

Parameters	Values (p.u.)
Over-voltage	+0.1
Under-voltage	-0.2
Over-frequency	+0.5
Under-frequency	-0.5
Over-current	+0.3

As the concept of MG is in the boom, so the classification of standards and stability parameters must figure out and standardized for reliable operation. In paper [7], the author presented various parameters for the stability of microgrid and classified them based on modes of operation and types of faults. However, certain barriers, which restrict the growth of the micro-grid, Soshinskaya *et al.* [8], categorized these barriers into four groups: protection and control, quality of power, mode of operation, and technical aspects.

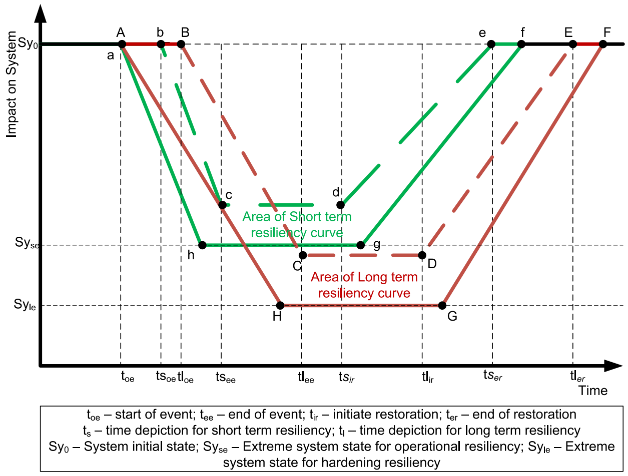


FIGURE 1. Short and long-time interval resiliency curve.

The connectivity of microgrid is imperative as it maintains the bi-directional power flow with a suitable communication channel. Numerous DGs play a vital role in maintaining the power flow, so peer-to-peer communication is used to increase the potential of communication between the micro-grids [9]. Also, communication with the help of time grading gives immense benefit to achieve the proper coordination between the relays [10]. The use of resilience in architecture reduces the resynchronization time and enhance the efficiency of the system. As per IEEE Std. 1547.4 [11], for powerful, reliable operation and control, the structure of current distribution can be converted into a micro-grid cluster using smart switches [2] and various algorithms.

However, the integration of renewable DGs with the grid does not work coherently due to its uncertain behavior. Therefore, during a natural disaster, the dependency index of renewable DGs becomes very low. It is evident from the literature that resiliency of the electrical network can be improved by: (a) hardening of electrical network components to reduce the failure probability of failure, (b) To improve the redundancy by the placement of new components or parallel power lines, (c) installing switches to extend the flexibility, (d) placing either conventional DGs or RES along with ESUs. Authors of paper [12], have modelled the resiliency on time interval viz. are short-term and long-term resiliency in terms of system state curve, as shown in figure 1.

The figure shows two curves, red curve is for long time interval resiliency, whereas green represents the short time interval resiliency curve. The solid line in both curves shows the impact on the system without resiliency planning, and the dotted line represents the impact on the system with resiliency planning. The curve is modelled in three-time zones viz. event on time (time of event/disaster), dead time (system remains degraded after the event), restoration time (time required to restore the system to normal state).

The length of line *'ab'* in figure 1, can be increased by forming resilient micro-grid architecture with suitable control and communication strategies, whereas the length of *'AB'* can be increased by placing sectionalizers and parallel lines along with applicable protection schemes. The slope of line 'bc' can be made sluggish by satisfying the critical loads during disaster time, using Energy Storage Unit (ESU) placed in MGs. The slope of 'BC' can be controlled by the intelligent operation of optimally placed sectionalizers for the survival of loads based on priority. Similarly, the slope of line 'de' & 'DE' can be improved by enhancing the developed strategies to be deployed for the restoration of the system.

Therefore, this article reviews the latest scenario of the micro-grid architecture and control strategies with various communication links to enhance the resiliency of the system against the low probability high impact natural disasters. Section 1, presents the introduction; section 2, reviews the general architecture with associated components and control techniques for the microgrid. The communication protocols and their significance with respect to different MG architecture have been substantiated in section 3. Section 4, elaborates the statement & purpose of distribution grid resiliency and role of sectionalizer to reduce the disaster impact on critical load.

II. GENERAL ARCHITECTURE DESCRIPTION

Earlier the term ''micro-grid'' was used for the remote situated grid where power supply from the main grid was not feasible due to economic or configuration point of view [13]. In recent times, realizing the positive impact on surroundings, stable, reliable power flow with the usage of natural resources available free of cost compelled the power authorities to update the conventional power system with renewable energy.

The concept of MG has implemented on a various scale in which low voltage grid, a feeder, and load is considered. The two main architectures of a microgrid are defined, one by CERTS, the American microgrid, and the other one are the European approach ''MICROGRIDS - Large Scale Integration of Microgeneration to Low Voltage Grids'' [14]. The CERTS concept has based on two functions: A smart source, which balances the power using power frequency drop, and stabilizes the voltage. It also provides a local zone of protection. A smart switch provides local information such as fault protection, standards for connecting distributed resources with the power system (IEEE 1547 event), intentional islanding, and automatic reclosure.

MG is integrated with the main grid with the help of Point of Common Coupling (PCC). PCC is a point at which MG can connect or disconnect with the main grid during normal or faulty conditions, respectively [15]. MG shifts its operation from the grid-connected to an islanded mode for maintaining a reliable and stable operation during the time of disturbance occurring at the main grid. Moreover, during this time, it provides continuous power to the critical loads by doing either load shedding or using enough storage power.

In the formation of microgrid, various elements such as Distributed Generators (DGs), storage devices, Circuit Breakers (CBs), Intelligent Switches (IS), Load Controller (LC), Micro-grid Central Controller (MGCC), reliable relays, AC and DC responsive and critical loads, inverter and rectifier are connected.

A. DISTRIBUTED GENERATORS (DG)

Institute of Electrical and Electronics Engineers Inc. (IEEE) defined the DG as ''The generation of electricity by facilities sufficiently smaller than central generating plants as to allow interconnection at nearly any point in a power system. DGs are a subset of distributed resources'' [16].

CIGRE and CIRED groups stated the DG concept as dispersed generators, which can be easily incorporated into the existing grid. A low power unit (10-50 MW) generator is considered a disperse generator [16]. The DGs are generally low power generation unit which generates less than 200 kW [17]. Mostly DGs are incorporate with advanced electronic interfaces for making the system flexible.

The literature reveals that DGs are the small power generation unit used to provide power to local or critical loads. For local loads, the DG unit operates separately, which can quickly provide power to small houses or other communities. However, for critical and tremendous power required loads, to obtain reliable power, DG units are connected to the main grid with the help of an intelligent electronics interface. These electronic element leads advantages to the network by reducing losses, reliable and makes system size compact.

However, various types of DGs are available in the market. Table 2 [16], [18]–[20] shows the comparison of various types of distributed generation in terms of power, efficiency, operation and maintenance cost, a life of service, Degree of Controllability (DOC) and CO_2 emission (lb/MWh) that signifies the impact on the environment.

B. BENEFITS AND CHALLENGES OF DG

The benefits with challenges of DG incorporation are mentioned in tabular form in table 3 [21], [22].

In above-mentioned table 3, the inclusion of DG in the power network definitely gives benefits to the grid system as it reduces the overloading capacity of the grid by providing the power to the grid and local loads. The location of DGs are mostly near to the load centre so the amount of losses into the system is very less. However, there are some challenges also associated with the penetration of DGs such as amount of harnessing the power from the resources due to their intermittent nature and complexity of power network.

C. ENERGY STORAGE SYSTEM (ESS)

Energy storage units (ESU) are the backbone of microgrid, used for maintaining the power imbalance between the supply end and the demand side. The system stability, reliability, power quality of the supply is maintained by the storage system [21]. Power quality tests for wind resources was introduced by Germany in 1992 [22]. Energy storage devices are

TABLE 2. Comparison of various type of distributed generation.

Distributed generators	Power	Efficiency (%)	Generator set cost($/kW)	Operation and maintenance cost($/kWh)	Servicing Life of generator (year)	Degree of Controllability	CO_2 emission (lb/MWh)
Diesel backup generator	20 kW-10 MW	36-43	125-300	26.5 $/kW/yr +0.000033($/kWh)	12.5	Controlled	1300-1700
Gas generator	50 kW-5 MW	28-42	250-600	26.5 $/kW/yr +0.000033($/kWh)	12.5	Controlled	-
Small Wind Turbines	10 kW-1 MW	25-40	-	5.7 $/kW/yr	12.5	Non/Partially Controlled	0
Large PV generator	50-500 kW	10-18	N/A	3.93 $/kW/yr	20	Non- Controlled	0
Solar PV generator (small scale)	kW-MW	Typical 10	N/A	14.3 $/kW/yr	20	Non-Controlled	0
Fuel Cells	50 kW-1 MW	35-55	1500-3000	0.035 $/kWh	5-10	Controllable	800-1400
CHP	Few kW-MW	30-40	-	-	20	Controllable	7-10 Mt/yr
Micro-turbine	30 kW-100 kW	20-30	350-750	0.005 – 0.010 $/kWh	20	Controllable	1300-1800

the key component for maintaining the continuous operation of power flow from micro-grid. Moreover, ESU placement in electrical grid can be used to decrease the slope of line 'bc' by satisfying the critical loads (figure 1). [23]. The main responsibility of the storage devices is split into three areas [24], [25]:

1. Due to lack of inertia, DGs will not be able to respond quickly to the associated problems such as variation in the loads or transients. Therefore, energy backup devices will maintain the power flow from the microgrid.
2. During transient fault condition, MG disconnects from the main grid and goes into islanding mode but due to energy devices, ride through capability is possible.
3. According to the requirement, MG works in two modes. One is grid connected and other is islanding mode. When transition from grid connected to islanding mode occurs, energy devices provide the initial energy.

The various energy storage technologies are available for balancing the power in microgrid such as batteries, super capacitors, fuel cell, flywheels, superconducting magnetic energy storage, CAES and many more. Among the storage devices batteries, flywheels and super-capacitors are mostly consider for microgrid system. Flywheel can be considered as a central storage device for the complete power system. For future demands batteries are good option as super capacitors would be a costly affair [25]. Figure 2, shows the different available storage technologies [26], [27].

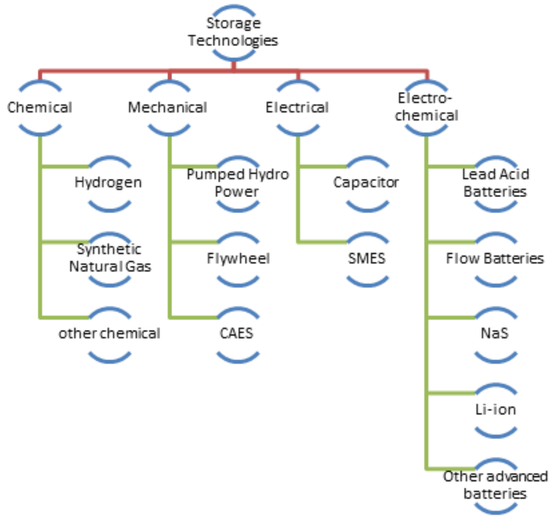


FIGURE 2. Storage technologies.

Presently numerous storage devices are available. Therefore, the basic understanding of selection of storage devices is required. Table 4 shows the various technical characteristics which includes efficiency of the battery, specific energy, power density, response time, life cycle, negative impact on environment with technical maturity and discharge rate of certain energy storage devices used in RE power system network [2], [18], [27]–[32].

Size of the energy storage is one of the concerned issue that has to be consider. To resolve this problem, power and

TABLE 3. Benefits and challenges of DG.

Benefits of DG	Challenges
1. Leads improvement of voltage profile	1. DG has Bi- directional power flow- protection coordination.
2. Lower the losses of the network.	2. Islanding mode endangers for the public as it leads overvoltage.
3. Reduce the burden on the transmission line by generating the power	3. Control system is complex.
4. Increase resiliency and reliability	4. Non- dispatchable units as output is intermittent in nature.
5. Require less space	5. Improper allocation cause losses, instability and overvoltage.
6. Environment friendly	6. Harmonics problem (Inverter End).

TABLE 4. Technical characteristics of energy storages.

Type	Efficiency (%)	Specific Energy (W h/kg)	Power Density(kW/m3)	Response time (ms)	Cycle life (cycles)	Cost ($/kW h)	Environmental Impact	Technical Maturity	Self-Discharge Rate(%/day)
Battery	60–80	20–200	0.1-10	30	200–2000	150–1300	Low	Mature/Commercializing	0.1-0.4
SMES	90–98	40–60	300.00–4,000.00	0.001-0.01 sec	1e6	High	Low	Early Commercial Demo/early Commercial Mature	10.00-15.00
Flywheel	95	200	40.00-2000.00	0.01Sec	10,000-100,000	1–140	Very Low	Mature/Commercializing Demo/early commercial Early Commercial Developed technology	24.00-100.00
Super-Capacitor	95	<50	15.00–4,500.	ms	0.001-0.01	250–350	Very Low	Proven/Commercializing	0.46-40.00
NaS	70	120		<100	2000	450		Market launch	
Fuel cell	30-40	500-3000(**W h/L**)		Sec-min	1000+	17-20	Very Low	Market launch	
CAES	48-54	2-6 **(W h/L)**	0.04-10.00	1 minute	8000-12,000	200-150,000	Medium/Low	Proven/Commercializing	0.0
Advanced adiabatic CAES	Upto70 %	2-6 **(W h/L)**	0.04-10.00	1 minute	8000-30,000	200-150,000	Medium/Low	Proven/Commercializing	0.0

energy density as well as specific power /energy indices curve is recommended as shown in fig. 3(a) [31] and 3(b) [28]. One shows a relationship between energy and power density, which clearly define the size of battery required in microgrid for reliable operation. If densities are higher, volume of energy storage will be smaller. Requirement of low volume are located right hand side corner at the top and high volume required devices in the bottom (left hand side corner) [31]. Similarly, specific power /energy indices represent the total power and energy on one unit of weight.

D. CLASSIFICATION OF MICROGRID

Microgrid classification are presented by various authors by considering the sustainable development and effective performance of the system, proper architecture and coordination

TABLE 5. Comparison of microgrid architecture.

TYPES	ARCHITECTURE	ADVANTAGE	DISADVANTAGE
1.AC MICROGRID WITH DC STORAGE	• Energy storage device are placed at separate DC bus. • Distributed generator and AC loads are place in AC bus. • Interconnection with Grids via static switch.	Robust to connect in several parallel ESS.	• Relatively complex structure • Power Quality issues as power factor, voltage with phase angle and frequency play a vital role.
2.DC REGIONAL MICROGRID	• DC feeder is connected with main AC bus. • Bi-directional AC/DC converters are used.	DC feeder can provide different voltage levels.	Complex
3.SOLID STATE TRANSFORMER BASED MICROGRID	• AC load is connected to the AC feeder. • DC loads and distributed generation are connected to DC feeder,	Standardized energy. Simple interface. Robust connection. Compatible with AC grid loads.	The decrease in reliability and efficiency of the system.

technique between the Distributed Resources (DR), MGCC and LC.

In paper [33], two configurations of microgrid i.e. low voltage AC and low voltage DC are incorporated into the main grid by considering sustainability and performance of the system. Also, author used multi-converter devices for the enhancement in the strength of the system. The classification of microgrid depends on various factors and author of [27], [33], shows the classification of microgrid based on four factors i.e. architecture, supervisory control, modes of operation and phases. Also, further sub-categories of MG architecture is presented in fig. 4(a) and types in 4(b).

From the literature, it is concluded that DC microgrid are less complex, easy to operate and cost effective as compared to AC microgrid. Due to limitation of DC microgrid, hybrid architecture is the best way to improve the reliability of the system. Table 5, shows the comparative analysis of the various structure of microgrid with pros and cons. According to the nature of requirement user can choose the MGs structure [34]–[39].

Also, Performance result of microgrid by considering the various parameters such as integration of RE, power quality, protection, reliability and cost is discussed in Table 6 [36], [38], [39].

From the table, as mentioned above, the conclusion has been made that DC microgrid is more reliable but limited to a certain extent.

E. CONTROL TECHNIQUES

Distribution generation needs natural resources as fuel, implying in increasing usage, resulting in more depletion of RE. The control strategies are required to improve the quality of the power flow in the microgrid as well as taken care of the available power. The various control strategies for AC microgrid are master-slave, peer-to-peer, hierarchical, and multi-agent control [39]. Summary of Pros and cons of control methods of AC microgrid and DC microgrid are given in table 7 [39]–[41] and table 8 [42]–[45] respectively.

It is concluded that frequency and reactive power issues are absent in DC, therefore controlling methods are easier as compared with AC microgrid.

III. COMMUNICATION TYPE

Architecture for the operation and control of microgrid requires an encrypted and reliable channel for successful operation. Encrypted communication across the microelements is the desired task. However, wired communication helps in short-distance data transmission; RS 232 and RS 385 are the most used ones [46], but with the increase in the size of the grid, wired data transmission is not advisable as it increases the complexity of the grid. So, opting internet communication protocol based on ISO or open system interconnection, transmission control protocol/internet protocol, and UDP/IP protocol ensures security and fast transmission of the data [47]. Table 9, summarized the various communication link available for microgrid with respect to coverage distance [48]–[57].

In addition, the microgrid structure has been categorized based on the range of communication into home area network (HAN), local area network (LAN), and wide area network (WAN). Table 11 shows that the transmission rate of 3G and LTE is faster compared with other networks [58] and applicable for HAN. MG control architecture has various power system devices embedded with Intelligent Electronic Devices (IEDs). Fig 5 shows the general communication within the microgrid consisting of the human machine interface server, IEDs, microcontroller, and DER [59].

IED receives the signals from the DER and transmit to microgrid controller. Then, microgrid controller generates the reference and control signals of voltage, current, frequency, real and reactive power to IEDs, which in turn send the control signal to DERs and the connected loads. Human machine

TABLE 6. **Comparison of the performance of microgrid architecture.**

Performance /Parameters	AC Microgrid with DC Storage	DC-Zonal Microgrid	Hybrid Micro-grid
Structure	• Complex	• Less Complex	• Complex
Integration with DERs	• Much difficult as various power conversion stages are required to integrate DC types of generators such as PV. • Synchronization of AC current is required.	• Quite easier	• Severe as three level hierarchy is used.
Interfacing with grid	• Connect easily with the grid using PCC	• Requires bidirectional converters	First using DC/DC or AC/DC converter and put DC onto Micro-grid and through inverter Connect easily with the grid using PCC.
Power quality/Stability	• Power factor, voltage magnitude, phase angle and frequency plays a vital role. These parameters must be taken care of. • Less stable due to synchronization factor.	• Voltage is the only concern. • High power quality. • More Stable.	Reactive and active power is separately controlled as well as during off-grid mode voltage should be taken care of.
Protection	• Can use existing techniques after the inclusion of some factors.	• Research on new techniques is going on.	• Research on new techniques is going on.
Reliability	• Less as compared with DC micro-grid as lots of converters and other devices are used, which leads to degradation of the power quality.	• Highly reliable with high power quality.	• Highly reliable with improved efficiency.
Cost	• Low as using existing wires and various devices.	• Low cost as fewer devices is required as compared with counterpart.	High as various advanced power electronics devices are required.

interface is used for monitoring, event recording, and controlling purposes.

The network has the following time zone, t_d = delay in propagation, t_s = duration of transmission, t_r = Time duration to pass on the incoming message to receiver's application and t_{max} = maximum delay. For an efficient data transmission the $t_d + t_s + t_r < t_{max}$ [60].

This communication is affected by various parameters such as speed, topology, and congestion status of the network and computational capability of IEDs hardware. The second transmission method is Power Line Carrier (PLC) in which power lines are used for the transfer of the data. It is efficient in terms of performance and cost. Some of the disadvantages of using PLC are noise, deviation, and signal attenuation risk [27], [61].

Now, every component of microgrid has some delay requirements. The efficiency of the system can be increased by decreasing the bottleneck, congestion, loss of data packets, etc.; to achieve the desired efficiency selection of protocols is the basic step. Some approximate delays are summarized in table 10 [62].

If the system exceeds the range of specified delay, it leads the electric malfunctioning in the microgrid. In this regard, Quality of Service (QoS) concept is provided, in which priority treatment is given for the system having critical delay so that information reached on proper time and reduced the loss of data [62]. In order to achieve it, the components have to be layered based on the requirement. The layering [48], [63]–[65] has been done, as shown in figure 6.

A. LAYERS OF COMMUNICATION CHANNEL

To communicate between the layers Internet Protocol base or non - Internet Protocols base is used. Internet-based protocols include Constrained Application Protocol (CoAP), Message Queuing Telemetry Transport (MQTT), 3G, LTE, Wi-Fi, whereas non - Internet Protocols include ZigBee based, z-wave based and Bluetooth [48], [63]–[65].

B. PHYSICAL LAYER

This layer consists of sensors, actuators, smart plug, smart meter, micro controller and storage. Based on the input data given by sensors, actuators perform the desired task, smart meter monitors the data given by sensors and controls the smart plug for transferring the power from the grid elements to the appliances. The interaction between the sensors, actuators, smart meter and plug with the computer is achieved using microcontroller, and storage units are used to store the processed data received from the sensors [63]–[65].

C. NETWORK LAYER

It is used to transfer the data from the physical layer to the application layer. These layers can be either wired or wireless. Wired includes cabled, or fiber optics, use of fiber optics prevents intervention by electromagnetic radiation. The wireless

TABLE 7. **Advantages and disadvantages of control methods of AC microgrid.**

Control methods	Pros	Cons	Suitability in resiliency enhancement. (On scale 1-3)	
			Technically	Economically
1. Master Slave	• It is suitable in both centralized and decentralized architecture. • With proper coordination between master and slave controller, survival time of microgrid will increase.	• Master controller should be taken care of as it leads the system into blackout situation. • Fast communication links of all DGs with master controller is required, for maintaining the reliability.	3	2
2. Peer to Peer	• Droop control characteristics plays the main role. • Communication link is required. • Low cost control method. • "Plug and Play" structure as no additional configurations are required.	• Controllers designing is difficult. • Less efficient. • Change in Balanced point happen because of load variation.	2	3
3. Hierarchical	• Different control levels are defined for maintaining the reliable power and operation. • Ensuring P/Q droop, deviation in frequency and voltage and at last marketing strategies. • Flexible in nature • Suitable for multi-microgrid architecture	• Not applicable in certain areas like remote rural. • Not economical in every aspect.	3	1
4. Multi Agent Control	• Similar to peer to peer control technique. • Each DG act as agent and communicate with the other agent for find out the mutual objective. • "Plug and Play" feature is applicable.	• It is suitable for decentralized architecture. • Integration of resources, Controllers, power storages or load into existing MAS controlled system is comparatively easy.	3	3

mode includes 3G, LTE, WiFi. The only disadvantage of the former with respect to the later is the loss of data; data loss might account for up-to 30% of the total data [66], [67].

D. CLOUD LAYER

The encryption of the data, retrieval of the data, and the management of the data occurs in this layer. The necessity of this layer arouses due to an increase in the amount of the data, loss of the data, and invasion of the privacy of the data [68], [69].

E. APPLICATION LAYER

It is the final layer, which the end-users see and use. This layer manages the consumption of energy and the pricing of the system. The functioning of this layer completely depends upon the other three layers.

Over the years, there has been significant development in wireless networks. Internet of Things (IoT) one such element, which has been turning around most of the theoretical applications to possibilities of achieving. One such application where IoT can be used is, in communication between various components across microgrid [70]. Using IoT, the most important factors of microgrid, namely, the efficiency of power generation and distribution is achieved [71]. Since the components of a microgrid are mostly non- homogeneous, various protocols have been used to achieve the desired requirement.

IV. RESILIENCE

A. NEED OF RESILIENT STRUCTURE

The occurrence of frequent natural disasters has caused damaged power lines, which takes a lot of time and money in restoration. Recent extreme cyclone events mentioned in table 11 [4], [72]–[81], the power and microgrid structure requires upgradation as distribution system are most vulnerable to natural disasters.

As mentioned in table 11, Fani cyclone hits Odisha in May 2019, with wind speed of 274 km/hr, damaged 8-power grid completely. 30 lakh of people in eight districts have been suffered from the darkness as power infrastructure was completely damaged, said by Odisha power secretary [72]. The damaged cost is more than 1200 crore in Indian

TABLE 8. **Pros and cons of control methods of DC microgrid.**

Control methods	Pros	Cons
1. Droop Control	• By changing the output voltage, load current will be balanced. • Using SOC of storage devices droop control, the power to be balance between various storing devices.	• The complex design of the controller.
2. Hierarchical Control	• Similar to AC hierarchical Control method, three levels are used. • Circulating current is eliminated caused by DC sources in first level and voltage compensation is provided in second control level. • Power flow between utility and micro-grid can be managed using tertiary control. • Much simpler than AC micro-grid.	• Similar to AC hierarchical Control method.
3. Hysteresis Control	• Fast dynamic response characteristics.	• Suitable for PFC and grid connected inverters. • Variable Switching frequency.
4. Voltage mode Control	• Duty cycle of converter is used for the adjustment of output voltage. • During grid-connected mode, DC link voltage is maintained using Voltage clamp control technique	• Small imbalances in output voltage leads injection of large DC current.
5. MPPT Control	• Commonly used technique because of stochastic nature. • Extract maximum energy. • Various algorithms are used for the implementation of MPPT control such as Fuzzy logic, P&O, ANN and Incremental Conductance.	• Different algorithm has different sensors and cost of implementation. Such as P&O has excellent efficiency.

currency [72]. Also, the power restoration time is around 1 to 2 weeks. A 33 kV, medium line (5030 km), and 11 kV, long line (38,613 km) transmission lines were broken due to fallen trees and wind speed [73]. Charging 33 kV and 11 kV lines at high temperatures with the maximum humidity environment of Odisha is a tedious task. Fani cyclone is much stronger than titli that hits the coast in October 2018, which costs less damage than fani. A similar disaster had occurred in Chennai, December 2016, which cost the total damage nearly Rs. 22,573 crore [73]. Recently Amphan cyclone hits the region costing damage of US$13.2 billion [83], [84].

The conclusion is that the coastal area has always been affected by natural calamities like heavy rainfall, storm, cyclone, etc., and the damage or shutdown of power grids due to these disasters costing loss of millions. Therefore, it is time to improve the resiliency of the grid by considering the local environmental conditions. For improving resiliency, work on the networking of micro grid is needed.

B. RESILIENCY VS. RELIABILITY

Resiliency and reliability terms seem the same, but the resiliency of a system is the property of the object to return to the equilibrium position after significant disturbance in the environment, such as natural and human-made disasters. One of the significant advantages of microgrid is to sustain the absorption of renewables and the capacity of islanding. The self-healing process has to be simultaneously triggered at distribution and generation levels to enhance microgrid resiliency [75]. In practicality, various managerial approaches are used, and the promising statuses of the resources available are revised to assure the optimal islanding during any possible occurrence. There is a very minute difference between the reliability and resilience of the microgrid. The system's reliability is its ability to continuously supply power to the loads without disruption [76]. The main differences between resilience and reliability are given in table 12 [77].

C. MICROGRID: AN APPROACH TOWARDS A RESILIENT SYSTEM

Due to changes in climate, the frequency of natural disasters such as cyclones, floods, tornados, hurricanes, and others is likely to rise in the future, so work on resiliency towards power grid architecture is extremely important. Table 13 shows the impact of resiliency on microgrid architecture [4]. As per IEEE Std 1547.4, for robust, reliable operation and control, the structure of current distribution can be converted into multi microgrid using quick response and communication-based switches [2]. These intelligent switches can talk to other devices during fault conditions and restructure the system to minimize power loss by separating the faulted zone and becoming a microgrid.

MG is a promising solution for providing power to the loads during disturbance occur on the grid. As the generation

TABLE 9. Various communication channel.

Mode	Frequency Bands	Signal Rate	Power Consumption	Bandwidth	Expense	Application in the proposed microgrid	Role index in resiliency enhancement
Weightless	subGhz	0.1-25 MBPS	Low	3-10 miles	Low	Smart metering.	Low
LoRa	subGhz	Less than 50kbps	Low	1-2 miles	Moderate	Utility metering	Low
NB-IoT	subGhz	0-1 mbps	Moderate	1-10 miles	High	Facility management services.	Moderate
Wireless HART	2.4GHz	250 kbps	Moderate	Abs(300ft)	Moderate	Encryption of the data.	Moderate
WiFi	subGhz, 2.4-5 GHz	0-50 mbps	Moderate	< 250 feet	Low	Intercommunication between neighboring systems.	High
Z-wave	subGhz	30 kbps	Low	Abs(100feet)	Moderate	Smart metering.	Low
802.15.4	subGhz, 2.4GHz	40, 250 kbps	Low	>200 miles	Low	Equipment maintenance.	Moderate
SigFox	subGhz	Less than 1 kbps	Low	1-10 miles	Low	Monitoring power generation from the grid.	Moderate
ZigBee	2.4GHz	230 kbps	Low	Abs(300 feet)	Medium	Intra and inter communication between devices	High
LTE Cat 0/1	Cellular	0-10 mbps	Moderate	3-10 miles	High	Transmission of preprocessed data across the microgrid.	High
Bluetooth	2.4GHz	1-3 Mbps	Low	Abs(300 feet)	Low	Communication across the components of the microgrid.	High
3G	Cellular	10-30 mbps	High	1-8 miles	High	Autonomous interaction across the components.	High

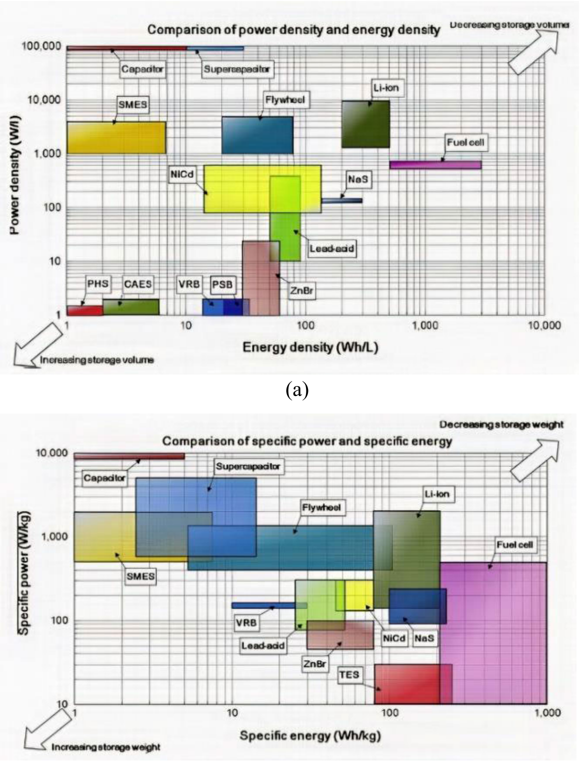
TABLE 10. Delay requirement in microgrid devices.

Microgrid Messages	Delay Requirement
Protection Information	4 ms
Monitoring Information	1 s
Control Information	16 ms – 100 ms
Operations and maintenance information	1 s
Messages requiring immediate actions at receiving IEds	1A:3 ms or 10 ms ; 20 ms or 100 ms
Continuous data streams from IEDs	3 ms or 10 ms

of the microgrid is very less around a few MVA [78], forming a multi-micro grid can surely enhance the resiliency for the critical load. In addition, the IEEE standard 1547.4 points out, operation and reliability of the distribution network can be improved by dividing the distribution system into multiple MGs [2]. In addition, for improving the system resiliency, the network must be upgraded from radial to mesh. So that if any disturbance occurs, power would be available from another generating unit and, hence, blackout condition can be avoided.

The ability of self-healing is becoming the most advanced feature in the smart grid, which enhance the resiliency and flexibility of the system. A various decision has been made towards resiliency. Some authors suggested that to improve the resiliency and reliability of the system, microgrid is the only way to use these advanced characteristics. An optimal Distribution System Restoration (DSR) plan is identified in paper [85] using a novel modified algorithm for enhancing the power network system resiliency. Author Yuan *et al.* [79] presented a self-healing approach based on a two-layer meta-heuristic technique for enhancing the resiliency of the grid. In the self-healing approach, the first layer finds the optimal restructuring of microgrid after a specific fault-using graph algorithm, and the second layer gives the status of DERs generation.

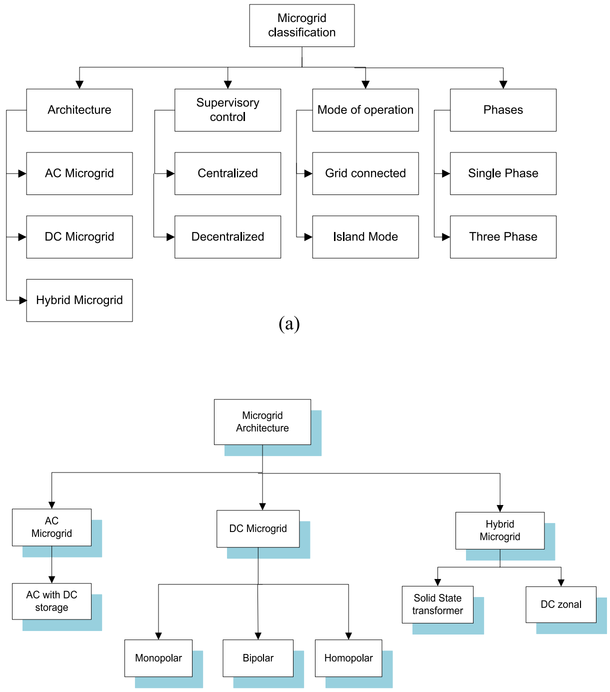
In a microgrid, whenever there is a sudden disruption of power, due to the presence of resiliency in the grid, the impact will be smaller, and the restoration will be quick. This proves that the supply will be continued even during the disruption. The disruptive events are not always expected or waited for, but when it occurs, the microgrid has to adapt to the situation



(a)

(b)

FIGURE 3. ***(a)*. Relation of energy density and power density. *(b)*. Relation of specific energy and specific power.**



(a)

(b)

FIGURE 4. (a). Microgrid classification. (b). Types of microgrid.

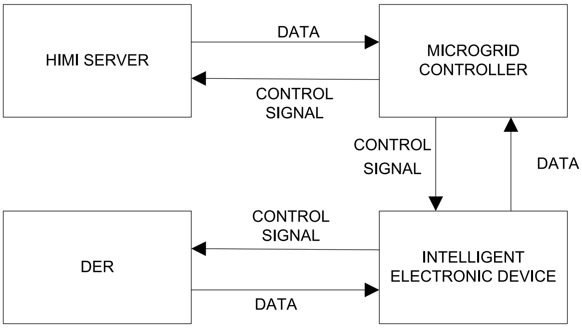


FIGURE 5. Data flow in microgrid.

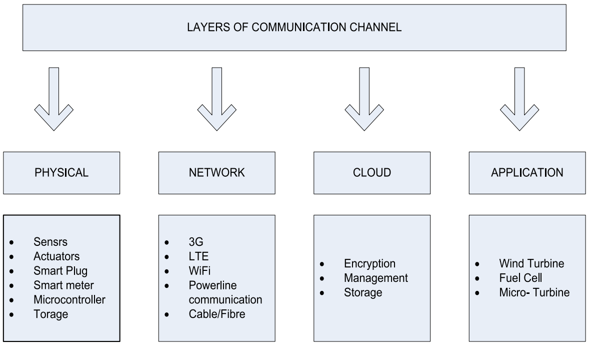


FIGURE 6. Various layering of communication channel.

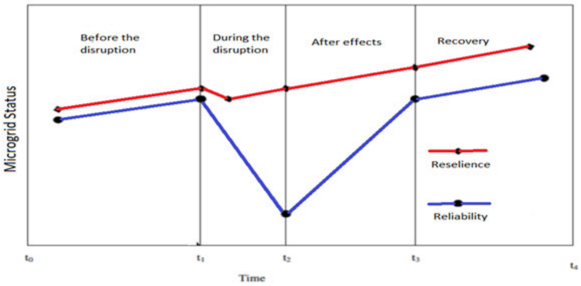


FIGURE 7. Graph of microgrid status vs. time (Comparison of Resilience and Reliability).

and perform the necessary actions for the non-stop supply of the power as shown in figure 7 [80].

When microgrid is used as a resiliency resource, the infrastructure specifications must be met. The major parts of infrastructure include lines, cables, switches, breakers, and transformer, which interconnect the various microgrid elements to the application loads. The microgrid with resilience can adapt to the various running generation units, and secure various less important units (obtained during power loss), which in turn increases the efficiency of the system. Resilience enhancement methods can be categorized into:

1. Enhancing the ability to adapt.
2. Enhancing the ability to recover.

The strategic planning stages and action during resiliency is describing in figure 8 [86], [87].

During the disaster, microgrid devices come in stage 1 of planning and decide which switches go into the off condition (disconnection) and then start operation, adapt the change in architecture, and lastly recovering stage [85]. After the fault clearance, the network goes into the recovering stage and becomes the normal grid.

MG becomes a microgrid resilient with the inclusion of long-term infrastructure reinforcement and short- term

TABLE 11. Recent extreme cyclone in India.

Vardah Cyclone	Titli Cyclone	Fani Cyclone	Vayu Cyclone	Amphan Cyclone
Year-2016	Year-2018	Year-2019	Year-2019	Year-2020
Wind Speed- 130 to 150 Km/hr.	Wind Speed- 150 Km/hr.	Wind Speed- 274 Km/hr.	Wind Speed – 150-165 km/hr.	Wind Speed- 250 Km/hr
No. of Uprooted electric poles- 10,000	No. of Uprooted electric poles- 100	No. of Uprooted electric poles- 15 lakh	No. of Uprooted electric poles- 566	No. of Uprooted electric poles- 4000
Transformer damaged: 800	15 transformers, damaged.	53 towers and 8 grids were completely damaged.	Total damage cost: $140,000 (2019 USD)	126,540 transformers, and 448 electrical substations were affected, total damage cost approx. (US$13.2 billion)

TABLE 12. Comparison of resilience and reliability.

Resilience	Reliability
Measures performance during less possible, high impact event.	Measures performance during high possible, low impact event.
Evaluated for specific threats.	Evaluated for all the threats
Measures the pre, during, post disaster effects.	Measures frequency and duration of power failure

TABLE 13. Impact of resiliency on architecture.

ARCHITECTURE	Impact during Disruptive Events/Absence of Resilience	Inclusion of Resilience
AC	No synchronization	Efficiency increases.
DC	Synchronization exists	Efficiency is higher than AC
Hybrid	Synchronization is not required as they are directly connected to AC/DC network	Highest efficiency as it is a composite of AC and DC

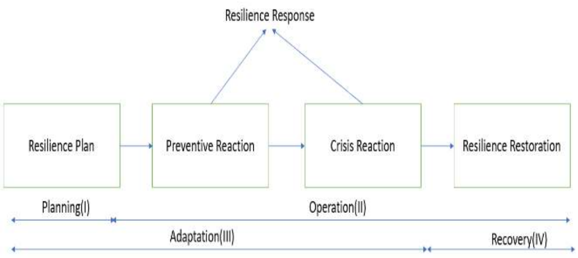


FIGURE 8. Resiliency stages.

operational effectiveness. These characteristics help in either reconfiguration of the power structure during the disaster and strengthen the structure or give corrective, preventive methods to mitigate the effect of calamities by transit into island mode or quick restoration. The reconfiguration of the structure is possible only with the help of a multi-microgrid. The further sub-division of long-term infrastructure reinforcement and short-term operational effectiveness is shown in figure 9(a) and 9(b). Infrastructure reinforcement considers the hardening and planning measures, which include underground lines, power conversion devices, etc., whereas, short- term operational effectiveness comprises prevention and correction action [76], [78].

Corrective actions include proactively change of mode of operation, microgrid clustering, restoration, curtailment. The enhancement of the resilience requires proper planning for the storage capacity and connection of DERs, redundant structure to adapt the change due to calamities, and proper correction methods if a disruption occurs so that avoidance of complete breakdown of the system can be possible. From various literature, a generalized flow chart is developed to understand the behavior of microgrid structure during normal and extreme disaster conditions in figure 10. The stepwise actions for resilient MG are as follows:

Step 1: The working status of the microgrid gets an update from the Intelligent Electronic Devices.

Step 2: Mode of operation of microgrid using a microgrid controller will initiate.

Step 3: If the microgrid is islanded, proceed to step 4, if not, it has to be disconnected from the main grid to make it islanded.

Step 4: If there are symptoms of the occurrence of a disaster, proceed to step 5, else stop the process.

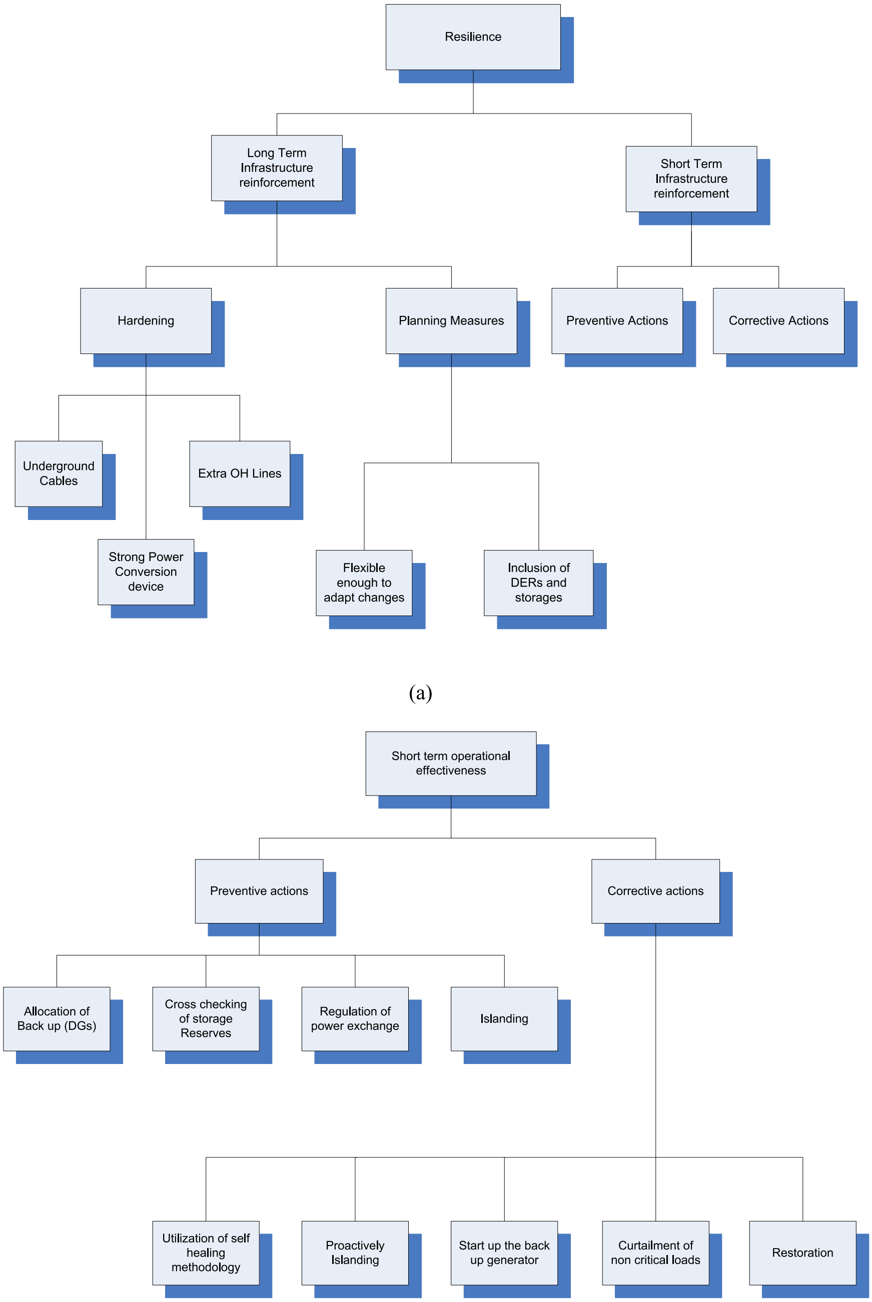
Step 5: Identify the optimum restoration scheme available for the microgrid to recover, if the scheme is not available, run the optimal search engine until an optimization technique satisfying all the preset objectives is derived.

Step 6: Based on the controller available, apply the derived scheme.

Step 7: If the required current is greater than the generated current, change the optimization technique, else continue the process.

Where I_g = ground current and I_r = reference value of current.

From the generalized flow chart, it is clear that microgrid withstands during a natural disaster by forming itself into a microgrid cluster.



(a)

(b)

FIGURE 9. **(a). Resilience enhancement measures. (b). Classification of short-term resilience measures.**

D. SECTIONALIZER AND FAULT PASSAGE INDICATOR (FPI)

From the above-generalized flow chart, it is clear that microgrid can withstand during a natural disaster by forming itself into a microgrid cluster using the optimizing technique. The formation of a microgrid cluster could be done using various algorithms suggested by authors in Table 14. One of them is using sectionalizer, shown in fig. 11 (a) and 11(b), and some are using sectionalizer switch with the inclusion of fault passage indicator (FPI). FPI is operated by its internal battery source. In addition, they can also be operated by solar power as shown in fig 13(a) [79] They are of two types, i.e., pole mounted and flight type as shown in fig 13(a) [79] and 13(b) [88] FPI internal circuitry has shown in fig. 13(c), in which LED is inserted, which will glow during an earth fault, reverse current or overcurrent fault condition, energized by the self-mounted battery. These FPI are works by sensing the magnetic field due to change in current. As shown in fig.13(c), the FPI signal system has two main sections. One

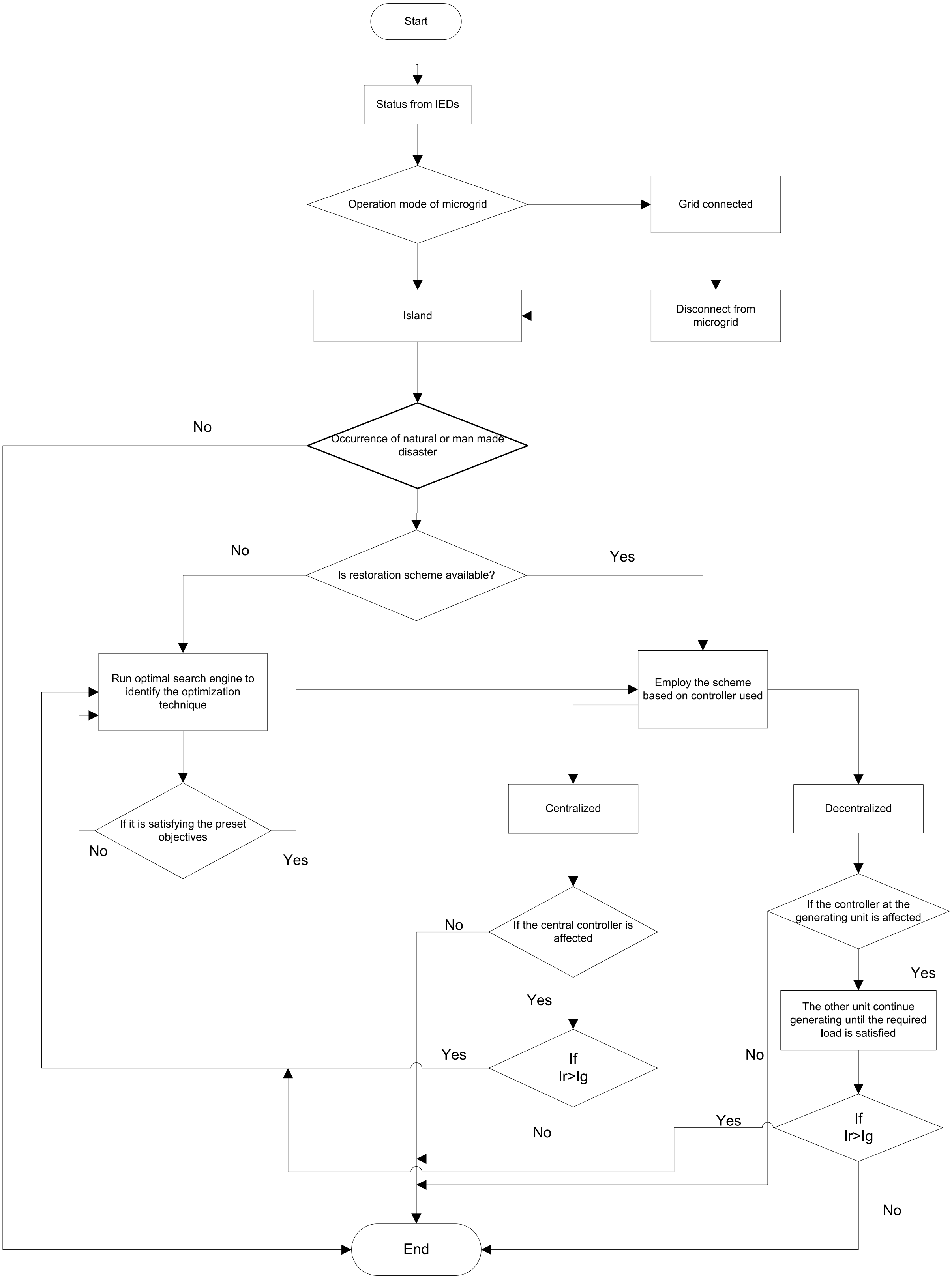
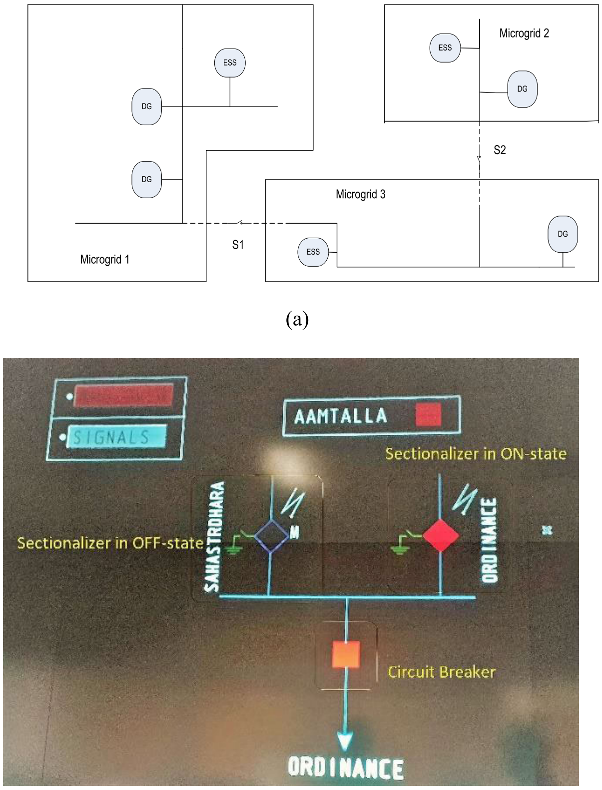


FIGURE 10. **Microgrid behavior during the normal and severe condition.**

is earth fault in phase indicator, and another one is overcurrent in the phase indicator. These FPI communicate with the SCADA center through the radio frequency signal. If the fault occurs, the FPI LED will glow and send the command



(a)

(a)

FIGURE 11. **(a). Microgrid formation using sectionalizer. (b). Location and mode of operation of sectionalizer on SCADA.**

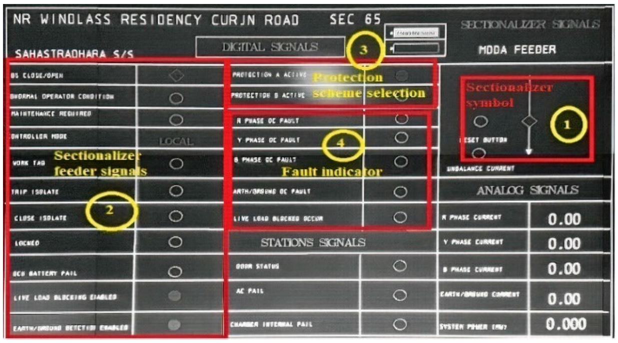
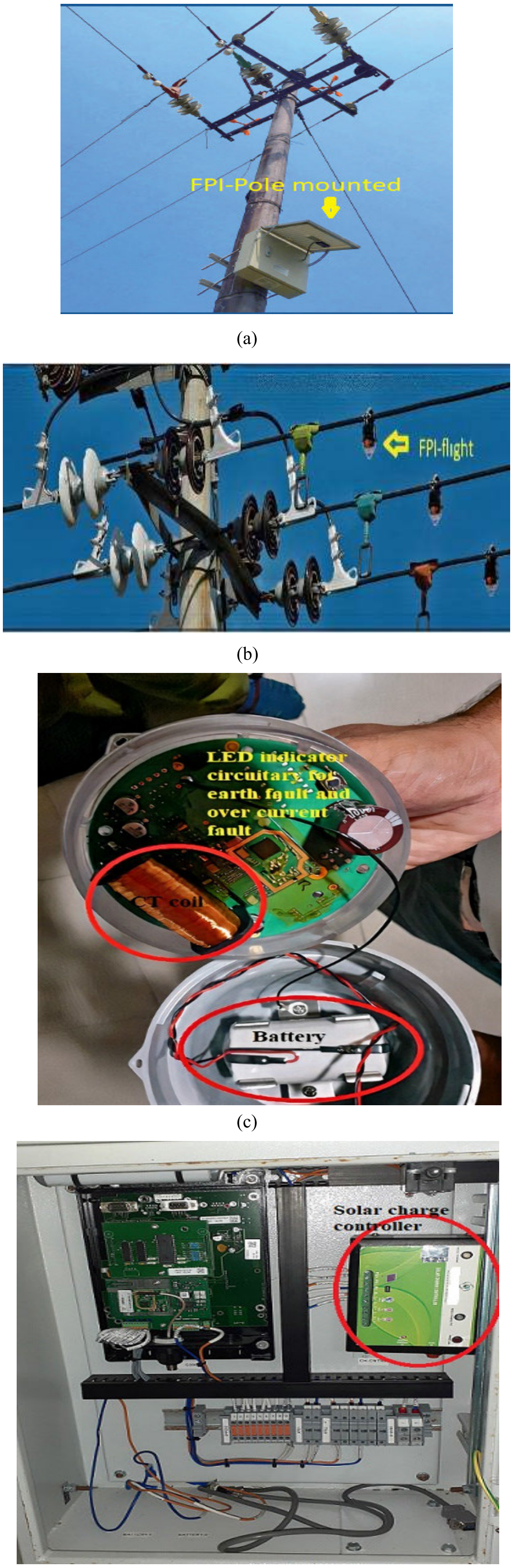

NR WINDLASS RESIDENCY CURJN ROAD SEC 65
SAHASTRADHARA S/S
DIGITAL SIGNALS
SECTIONALIZER SIGNALS
MDDA FEEDER
BS CLOSE/OPEN
ABNORMAL OPERATOR CONDITION
MAINTENANCE REQUIRED
CONTROLLER MODE LOCAL
WORK TAG
TRIP ISOLATE
CLOSE ISOLATE
LOCKED
ECU BATTERY FAIL
LIVE LOAD BLOCKING ENABLED
EARTH/GROUND DETECTION ENABLED
PROTECTION A ACTIVE
PROTECTION B ACTIVE
R PHASE OC FAULT
Y PHASE OC FAULT
B PHASE OC FAULT
EARTH/GROUND OC FAULT
LIVE LOAD BLOCKED OCCUR
STATIONS SIGNALS
DOOR STATUS
AC FAIL
CHARGER INTERNAL FAIL
RESET BUTTON
UNBALANCE CURRENT
ANALOG SIGNALS
R PHASE CURRENT 0.00
Y PHASE CURRENT 0.00
B PHASE CURRENT 0.00
EARTH/GROUND CURRENT 0.00
SYSTEM POWER (KW) 0.000

FIGURE 12. **Sectionalizer signals.**

to the SCADA center by RF signal. The SCADA center receiver.

Sectionalizer methodology with the Fault passage indicator provides a robust option to implement various protection schemes based on weather and operating conditions. In figure 11(a), S1 and S2 are the sectionalizing switches on location 1 and 2 respectively on the distribution line. At the time of occurrence of fault, sectionalizer S1 and S2 switches will be opened, and the whole microgrid segregated into three independent microgrids. The operation of sectionalizer switches depends on algorithms such as graph theory [89]. The location of the sectionalizer switch is the



(a)

(b)

(c)

(d)

FIGURE 13. **(a). Solar-powered pole mounted FPI. (b). Flight FPI. (c). FPI-flight circuitry. (d). FPI-receiver circuitry.**

TABLE 14. Summary of decision variables and its corresponding constraints from the literature.

Reference	Optimization technique	Objective Function Variables	Constraints	Conclusion	Test system	Resiliency addressed	
						Direct	Indirect
Wang, Longjun, *et al. (2020)*	Mixed-integer programming	To minimize the costs of investment, maintenance, and customer interruption.	i) Only one sectionalizer switch can be installed in a location. ii) Remote controlled switch and fault indicators are not installed at one location.	70% failure due to distribution equipment is considered. Also, the proposed method shows the reduction in time consumption for the location of fault with the help of sectionalizers and fault indicators.	IEEE-33		✓
Zadsar, Masoud, *et al. (2017)*	Self-healing (Resiliency) approach based on a two-layer metaheuristic algorithm	i) Optimal formation of microgrid using graph algorithm (Switching) ii) Optimal DERs generation	i) Radial system ii) Finding electricity trade iii) Voltage and line thermal limits. Storage and Microturbine thermal unit	1. Central management autonomous controller was used. So, useful only for the central control system 2. Self-healing modes presented using graph theory 3. Search and running time is reduced for finding optimal structure.	IEEE-33	✓	
Hussain, Akhtar, et al. (2017)	Resilience-oriented optimization/Robust	i) Minimization of operation cost using the proposed index, Consensus-based algorithm is used for load shedding	i) Power limit, resiliency index limit	1. Resilience index was presented to feed maximum critical load for hybrid system only during emergency mode. 2. Load shedding was done to feed more critical loads.		✓	
Gao, Haixiang et al. (2016)	Chance constrained program and continuous operating time	First maximizing Resiliency: $\max \sum_{c\epsilon C}(Wc \cdot P_c^N \cdot T_c^R)$ and, second minimization of deviation in voltage of critical load during the restoration	Service time, generation resources, power flows, and radial system	resilience-oriented critical load restoration	IEEE-123	✓	
Balasubramaniam, Karthikeyan, et al. (2016)	Nonlinear programming	Minimize the load shedding and increase the non-critical service during the fault event.	Voltage range, real and reactive power for generator range, ramp limit, demand response and lastly Storage limit	1. Calculation of uncertainty of RE generation and load forecasting using probability distribution function and confidence level was considered.	13 Buses		✓
Wang, Zhaoyu, et al. (2015)	Mixed Integer non-linear programming	a) Minimization of operation costs of distribution system during normal mode b) Maintain reliable supply during self-healing mode in the fault affected areas.	1. Power exchange 2. Voltage level at each node=0.05 3. Output of inverter limit 4. SOC	1. The self-healing optimization techniques were designed and developed for the extreme climatic conditions.	IEEE-123		✓

TABLE 14. ***(Continued.)*** **Summary of decision variables and its corresponding constraints from the literature.**

Chen, Chen, et al. (2015)	Mixed Integer linear programming	Micrograds formation so that maximum loads get supply after natural disasters with optimization.	i) Node clustering: $\sum v_{ik}$ $if\ v_{ik} = 1,$ $node\ i\ belongs\ to\ k\ microgri$ ii) Microgrid connection $v_{ik} \le v_{hk}$ iii) Microgrid branch node $C_{ij} = \sum v_{hk}$ Where i,j =lines K=set of microgrids h= children node of line(i,j) iv) Microgrid load pick up: If any node is energized by any microgrid from the set the two conditions should be followed, (i) $v_{ik} = 1$ (ii) Switch should be closed for power flow, S_i =1. v) Microgrid Operation: Power flow and voltage limit vi) Distribution System Condition: Separate faulty lines and faulty switches.	1. For the restoration of critical loads- remotely controlled switches were used. 2. For resilient communication –a multi-agent coordination scheme was designed.	IEEE-123	✓	
Wang, Zhaoyu .(2015)	Rolling-horizon optimization	1. Minimize the cost and maximize the revenue during normal conditions. 2. Optimal sectionalized the on-outage area into cluster microgrid during the fault.	Power exchange, Voltage limit, Output of inverter limit, SOC limit=0.9 and charging/discharging limit=50%of the size, generated energy=consumption	For predication -Monte Carlo simulation is used to shows the prediction error. In the self-healing, a fault was considered with the clearance time of 1.5 hr, but during the extreme disaster, various damages to the system can happen. So, multiple faults at the same can be considered by increasing the time.	IEEE-123		✓
Pashajavid (2015)	Model predictive control and Hierarchical outage management scheme are proposed.	1. Minimization of total costs of microgrid Minimize the cost of load curtailment	1. Power balance, ramping, and output power limit of dispatchable unit, storage unit range, load curtailment.		------		✓
Khodaei (2014)	Mixed-integer (normal operation) and linear programming(resilient operation)	Minimization of load curtailment	1. Power from DER and main grid power should be matched (hourly) 2. Energy storage power should be in limit. 3. Uncertainty regarding interruption of power grid supply	Proposed Resiliency oriented microgrid optimal scheduling model. Centralized scheduling was considered.			✓
Gouveia, C. (2013)	Online tool	Minimizing the load shedding and taking care of storage so that frequency could be in control.	Storage capacity, power balance, and frequency range.	Applicable for less than one hour, only otherwise forecasting and complementary approach would be included.	--------		✓

main concern for reducing the fault location time. As a cost point of view, the installation of sectionalizes and fault passage indicators on each feeder is not worth it. Hence, the optimal placement of sectionalizer and fault passage indicator is formulated using a heuristic algorithm, including simulated annealing [90] ant colony [91], memetic [92] and genetic algorithm [93]. While the main disadvantage of the heuristic algorithm is taking more run time as shown in paper [94]. To overcome the run time, the author [95] proposed a mixed integer programming for the placement of sectionalizer switch and fault indicator. In paper [94] and [90], the optimal location of the sectionalizer and fault passage indicator is calculated using PSO and GA, respectively. Also, in ref. [96], deployment of fault indicator is identified by considering the existing control and protection devices into the system. The author [97], presented a relationship matrix of line current vs. location of fault for reducing the restoration time of supply. Recently in ref [98], the author presented a three-matrix position-based analysis using mixed-integer programming by taking the consideration of cost-benefit and reliability evaluation of customer interruption time on IEEE 33 bus system and validate the result on real urban distribution system.

Figure 11(b) shows the real-time operation of sectionalizer on SCADA of the Aamtalla area of Dehradun, India. Two feeder lines, one from Sahastrdhara and others from the ordinance are incorporated with sectionalizer. The symbol red in color of the feeder ordinance shows the ON state mode of sectionalizer that indicates the normal current flowing in the feeder line. However, the Sahastrdhara feeder sectionalizer indicates the OFF state mode, because a reverse value of current flowing through the fault indicator, which sends the signal to the SCADA system and operators sectionalized that particular feeder sectionalizer. In OFF state mode, the sectionalizer switch disconnects the faulty feeder from the healthy section.

A survey regarding the operation and location of the sectionalizer switch is conducted in URJA BHAWAN, Dehradun, India. Figure 12 shows the real-time various operating signals of sectionalizer on the SCADA system. For clarity purposes, the SCADA screen shown in this article is marked into four zones. These are sectionalizer symbol zone, feeder signals, protection scheme selection, and fault indicator. The first zone denotes the sectionalizer symbol. The second zone on the screen shows various feeder signals that give the indication of the feeder whether feeder is in the operating mode or maintenance mode etc. The third zone shows the protection scheme selection based on the operating season (protection A scheme for summer and protection B scheme for winter), which is already specified according to the consumption of the energy. And the last zone marked on the screen is the fault indicator. The flow of overcurrent in the particular phase is indicated by the fault indicator section. If the fault occurred on a particular phase, the indicator would glow, and the command will generate for the energization of sectionalizer switch. After receiving the command, sectionalizer switches operate and isolate the faulty section by reconstructing the network with the help of RE.

To increase the life of FPI flight type battery, distribution engineers generally program the FPI flight to glow up to 2-3 hours. However, during a disaster, it could be a disadvantage. Hence, FPI can be operated by a rechargeable battery with a flexible solar PV panel on the outer surface of the FPI flight. Various approaches to solve the resilient structure problem are combine and presented in tabular form in table 14 with the objective function and optimization technique.

Microgrid controller plays a vital role in managing microgrid cluster such as supervising the local controllers, monitoring, and controlling the various functions. The microgrid controller also supervises by a central Distribution System Operator (DSO) using a bidirectional strong and secure channel.

TABLE 15. Advantages of mesh topology over the radial.

Radial Structure	Meshed Structure
The structure is unidirectional; any fault in the system leads to massive power loss.	More flexible than radial in terms of power loss, power quality, cope with the load growth, and improved voltage profile.
For reliability enhancement, emergency tie lines with an open switch are provided.	For reliability enhancement, the optimal number and position of various distributed generations can be deployed with sectionalizer switches.
The number of tie lines is increased leads to congestion.	Optimization of a complete system makes system congestion-free in the future.
The end distributor near to the substation gets heavily loaded due to which the consumer at the other end might face voltage fluctuation issue.	This topology will help us to mitigate serious voltage fluctuations hence improving the system resiliency.
Dependent on a single feeder and distributor. Any fault will cause interrupted supply for all the consumers.	Fewer power outages will also lead to improved system resiliency.

E. PROTECTION SCHEMES IN RADIAL AND MESHED NETWORK

Now, it is evident that to improve the system resiliency, the network must be upgraded from radial to mesh, as a meshed network enhances the reliability. The advantage and flexibility of mesh topology over radial are defined in table 15.

The issues that might face while changing the radial network into the mesh connected network are the reverse power flow, excessive fault currents voltage regulation and violation, protection, and reliability, and so on. The major issue that should take into consideration is the protection of the system. Protection is a must in networking, and while changing the topology, this issue is of great importance and needs to be dealt with. The potential problem that may occur while changing protection schemes is regarding the control of real or reactive power across the normally-open point during a fault. For protection, only one circuit breaker with overcurrent protection relay is sufficient per feeder in radial connection, but while changing the topology, it may require more number of circuit breakers per feeder which is a difficult task since there might be miscoordination due to their operation and will be non-economical as per the protection cost. The

TABLE 16. **The challenges faced by protection devices in the mesh topology.**

S. No.	Topology/Mode	Reasons	Issue Faced by protection devices.
1.	Islanding	Short circuit levels drop in islanding	The protection system will not respond to the fault as they are already designed with high short circuit levels.
2.	Mesh	Mostly generation sources, connected with converters.	All the converters designed with the limited value of current, during fault converter, protect itself so proper operation of protection devices is not possible.
3.	Mesh/ Radial	Due to the intermittent behavior of DGs, variation in fault levels	Difficult to operate current based conventional protection devices.
4.	Mesh	Due to the short segment of the line, fault sense by the relay is not correct.	Fault detection and disconnection are difficult without strong communication links.
5.	Mesh	Incorporation of critical loads	The protection system will not respond to the fault as they are already designed with high short circuit levels.

issues and challenges faced by protection devices during the transition from grid connected mode to other modes are presented in table 16.

Mostly existing distribution systems are radial where the power flow direction is unidirectional with conventional protection scheme, whereas incorporation of DG converting the existing system into mesh topology leads to change in the source impedance, short circuit level, and direction or magnitude of fault. Therefore, the mesh system needs a modified protection scheme with strong communication links between the devices. With the continuous progress of technology and natural disaster scenario, deployment of different types of distributed generation is the solution, which serves the critical loads by connecting the tie line switches or sectionalizer switches in the feeder and location of these switches can be calculated using an optimization technique. During a natural disaster, for the survival of critical loads, power can be supply from the distributed generation. At the same time, the incorporation of distributed generation makes existing radial distribution system into mesh topology. Below are the points that show the reliability of the mesh topology.

1. 70% to 80% of faults in distribution are due to system equipment. The addition of distributed generation makes the system robust as a power failure in the network will no longer be the issue.

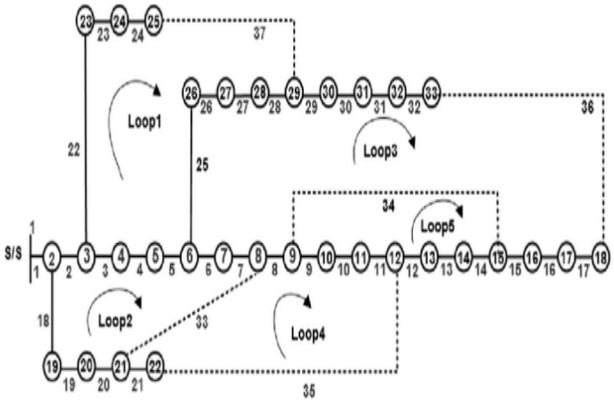


FIGURE 14. **IEEE-33 radial to mesh formation with sectionalizers and parallel lines.**

2. As shown in figure14, by connecting the tie lines switches, i.e., 33, 34, 35, 36, 37 system will become mesh type and start feeding the power to the healthy areas during the unavailability of the grid.

After getting the location of critical loads, the optimal placement of sectionalizers, along with parallel lines or hardening the system, has been presented in the literature. Therefore, the radial network will get converted into many small meshed microgrids, as shown in the figure14 [99], which will enhance the survival of critical loads.

Various sensitive relays and circuit breakers are used to tackle the electrical fault in the radial and mesh connected system. Distance protection is mainly applied in radial distribution, but the deployment of DG into the distribution system imposes the reconsideration of existing protection scheme since infeed or outfeed of DGs current and fault resistance badly affect the performance of distance protection in the mesh network. To mitigate this effect, an adaptive distance protection scheme is presented in paper [100] by considering the DG in the radial feeder. Despite the notable advantages, distance protection is still problematic in a mesh connected network. However, various authors presented highly reliable and promising schemes to deal with the power flow in the meshed network such as multi-relay scheme using directional overcurrent relays [101], [102], communication-based adaptive directional overcurrent protection scheme [103], [104] and pilot directional overcurrent protection scheme [105]. However, for the protection of each line segment, an advanced differential protection method has been considered in mesh connected by the author [106]. Unlike radial, providing protection in the mesh system is quite difficult due to new power generation sources, which change the magnitude and direction of current flow. In paper [107], the author applied an algorithm on 30 and 39 bus systems of standard IEEE test systems; for finding the critical clearing time by considering the reconfiguration of the network and time taken by the circuit breaker operation. Also, the result shows that the transient stability of the synchronous generator is improved. At last, the conclusion is made by the author that communication is the best way to improve the protection devices operation successfully. A fault data-sheet is generated by considering the various situation for tests, and an intelligent time-time transform protection scheme with a deep belief network has been developed and tested to protect microgrid during fault conditions [108]. In addition, the effect of communication delay, noise, high impedance fault detection, and back up protection is also evaluated to make scheme robust.

V. RESULT & DISCUSSION

The literature has suggested various methods of enhancing the resiliency, upon reviewing, the following points were identified as scope for the future work:

a. Healing strategies during the disaster have been mentioned; the systematic timing of switching operations must be implemented in the system as well.
b. The increase in the occurrence of the disasters necessitates consideration of the real-time data rather than assuming in building a resilient microgrid.
c. The work on AC decentralized microgrid has to be increased, in order to face the occurrence of the disaster at any point of time.
d. The scope for work on communication across various devices of the microgrid has to be increased.
e. Wireless communication increases efficiency and reduces labor. So, IoTs applications can play a vital role in microgrid clustering formation.
f. As shown in fig. 16, sectionalizer enhances the resiliency of the system, but the location of the sectionalizer between the feeder is the main concern to work upon.

VI. CONCLUSION

The frequent occurrence of disasters in recent times is posing a compelling challenge to power engineers to make an efficient, resilient structure. This article reviews the various architectures of the microgrid with their technical specifications. The elements under consideration are distributed generations and energy storage systems. The focus is on the comparison of the architecture with their control methods to judge which architecture is suitable and can be considered for making a resilient microgrid system. The optimal method found is the use of a hybrid system with smart switches, as AC is more flexible to reconfigure during the disaster, and DC microgrid feeds the local loads. In addition, forming a multi-microgrid using smart switches is the best architecture to enhance the resilience with decentralized control to maintain the reliability of the system. This article also highlights the various protocols used in communication layers and delay requirements between the devices of the microgrid. The work on communication requires more effort as resilience enhancement depends on communication between the devices. To add on, various frequency-range communication links are available for the microgrid devices, which helps in improving the restoration time. IoT is the new technology that can be implemented in the microgrid device.

The minute difference between reliability and resiliency is pointed out in the paper. Resilience enhancement is used for the smooth functioning of the microgrid during the disaster. Various resiliency enhancement measures are described in the paper, and the study reveals that resiliency can be categorized into long-term, that deals with architecture or restructure the system, and short-term resiliency with operational effectiveness but resilience enhancement of the grid is not possible without networked microgrid. In the resilient structure, microgrid sectionalized into multi microgrid using various optimization techniques is analyzed in the paper. The future work may include designing a distribution grid by considering the real data rather than the assumption to make a resilient oriented system using the optimization technique.

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