International Journal of Engineering & Technology, 7 (2.8) (2018) 35-41

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research Paper

A comprehensive study on protection, control and communication techniques: a key concept for microgrid intelligent operation

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Abstract

Microgrid is an integrated network of renewable and non renewable resources to supply the green power to a small range of community. An effective communication technology is necessary to be implemented among the power generations, storages and loads of microgrid in order to manage the load sharing, shedding and protection issues. This paper provides the study on architecture, characteristics, load managements, protection schemes, communication techniques and research challenges of microgrid.

Keywords: *Renewable Resources; Microgrid; Communication; Management; Protection; Research Challenges; ETC.*

1. Introduction

The utility grid is structured with three network systems such as, power generation, power transmission and power distribution. Here, the transmission network is delivering the generated power to distribution substation then the power will be distributed to consumers. A substantial amount of generated power is wasted as heat due to the long distance transmission and improper utilizations. Therefore, the smart grid is necessary to be implemented with power system in order to balance the energy generation and consumption [1]. A smartgrid is comprises the advanced sensing and actuator technology, intelligent control algorithms, effective communication infrastructure and self diagnosis for restoring power outrages [5]. The smartgrid structure is to have two ways communication between utility grid and consumers in order to supports protective operations, but the real time factors such as reliability, scalability and security are the major issues when it is come for the implementation. So that, the system has to be implemented with the facilities of local generation and storage at near the consumption premises and the name for the system is given as 'Microgrid'. A microgrid is comprises low voltage distribution system with distributed energy resources together with storage devices and flexible loads [2] and the integration of distributed generation units (DG) will affect the quality of the power and increase the voltage range in the grid by injecting the active power [3]. The implementations of microgrids are beneficial to the small community such as commercial facilities, residential and university campuses by applying the intelligent management to supply the connected loads and optimizing the energy usage [4]. As the use of renewable energy increases the system will be complicated to integrate and control the entire operations. So that, the communication infrastructure playing the major role in the microgrid to increase the grid integrity and stability. Figure 1 shows the implementation of a future microgrid with centralized management and wireless communications.

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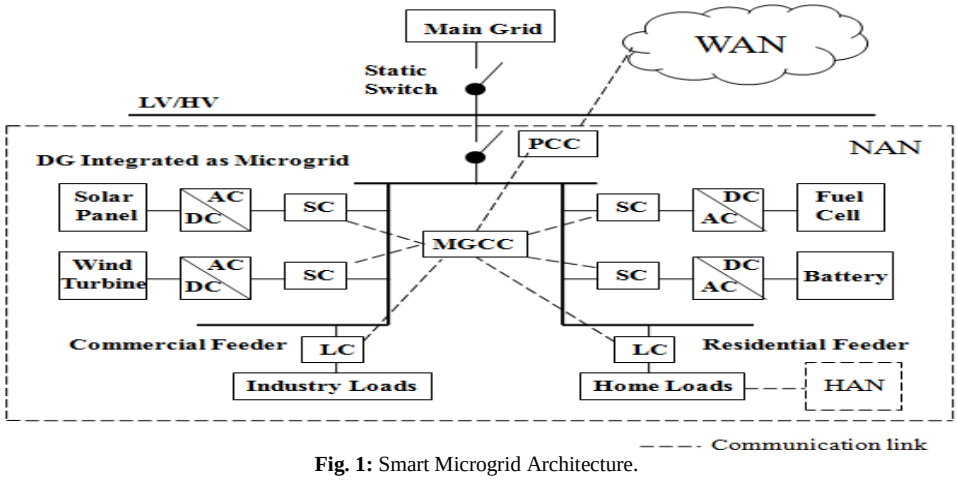


Fig. 1: Smart Microgrid Architecture.

An integrated distributed energy network combines the electrical power electronic converters and controllers for intelligent management. The primary controller of a microgrid is MGCC (Microgrid Central Controller) which responsible for managing high – level tasks. The Point of Common Coupling (PCC) is normally a static switch to connect the microgrid with utility grid. Source and Load controllers (SC and LC) are the secondary level controllers to connect the different generation units to the feeders based on power demands [8].

2. Microgrid characteristics

A microgrid is a local power system which equipped with generation, loads and demand all together connected in a controlled network. The microgrid can operate on grid connected mode and it can also be operate on independently (island mode). When a microgrid is operating on island mode it can be act as a self sustaining power system and demand has modulated through an intelligent control system which adopted by demand response (DR)[7]. In order to provide smooth and reliable flow of the power a microgrid incorporates some of the following principal characteristics.

- Must be facilitated by self healing mechanism in order to detect, analyze and respond to the fault.
- The microgrid management system must be user friendly and make the customers to participate into grid operations.
- Microgrid power system should be delivering the green power that satisfies the power consumers.
- An intelligent system which implemented with a microgrid should be resilient to cyber and physical attacks.
- The microgrid power network must be structured with plug and play approach in order to accommodate variety of distributed generation (DR) and storage options.

By the virtue of being a self automated system, a microgrid is resilient to the power supply interruptions and the timeframe of this characteristics differ from a system which operate on grid independent mode and it can operate for long period depends on the availability of renewable energy. The penetration of renewable sources brings more benefits to the grid in terms of delivering the sustainable power and setting up the schedule with a range of demand requirements and by shedding the non critical demands the system can manage the critical loads. In microgrid the conversion losses avoided by feeding DC loads using DC sources such photovoltaic system and the distribution network losses reduced by the local use of energy [6].

3. Microgrid load management

The total loads of a microgrid can be measured easily as the sum of energy generated by DG and the amount of energy imported through PCC (Point of Coupling). When a microgrid is operated on grid connected mode, often the distributed generation is less than the microgrid total load due to the maintenance of generators or the economics on power production [9]. The loads such as, heaters, refrigerators, freezers, air conditioners, etc. of a distributed power system are controlled by load management programs (LMP) including direct load control (DLC) and interruptible load management (ILM). Other loads like battery, heat storage unit and vehicle to grid (V2G) are taking major part in the LPM [11], [13]. A large number of distributed generations (DG's) and renewable energy resources (RES) can be connected to the utility grid with the help of smart grid technology but, the necessary development is needed in managing the distribution network when large numbers of RES are integrated. It can be done with the help of microgrid (MG) and virtual power plant (VPP) concepts [12]. Authors Jingshuang Shen,t Bosong Li has discussed about various controllable loads and types of load management approaches in [47].

Type I of Controllable loads: This includes residential loads such as, water heater, air conditioner; refrigerator, washing machine etc. and these are interrupted by load utility monitor and the load curves can be modified by reducing the demand. These are the loads can be called as passive controllable loads, because it cannot inject the power to utility grid at any time [47].

Type II of Controllable loads: These types of loads are active controllable loads includes CCHP (Combine Cooling Heating Power) and Vehicle to Grid etc. It can be inject the power to grid, addition it has the flexibility to schedule as controllable loads [47], [48].

Type II of Controllable loads: These types of loads are broad controllable loads includes microgrid and VPP etc. Although, the microgrid and VPP are integrated with DGs, storage device, renewable sources etc. They are mainly demanding the power from the utility grid during grid connected mode [47].

DLC (Direct Load Control), ILM (Interruptible Load Management) are the common load management strategy in distributed power system. DLC can easily reshape the load curve by cycling the large current appliances at the user side such as, water heaters, freezers, heaters etc. However, interruptible loads are noticeable at the consumer side, but generally the DLC can be controlled it without noticeable on consumers i.e. the system monitors the utility and sends an ON/OFF commands directly to smart appliances [55]. The deployment of smart meters in the microgrid facilitates the customers to participate in DSM (Demand Side Management) by the development of real time communication between smart devices and distributor. DLC strategy is mainly focusing on demand response and renewable energy like solar and wind power.

Authors Wei Huang, Miao Lu, Li Zhang are discussed many control strategy in reference [56] and are summarized as central bi level control, aggregator and hybrid coordination control. A microgrid may include with different types of controllable loads, but bi level control strategy is only suitable for the loads which are having same characteristics. Aggregator is serving as a central controller, it collecting information from the grid and controllable loads and also it provide regulated management by connecting grid operator and smart appliances. Table 1 shows the summary of controllable loads.

Table 1: Summary of the Controllable Loads [9 – 13, 44 – 56].

Item	DLC	Interruptible load	Store battery	V2G	CCHP
Power	Passive	Passive	Active	Active	Active
Store excess energy	No	No	Yes	Yes	Yes
Send energy to grid	No	No	Yes	Yes	Yes
Peak saving	Yes	Yes	Yes	Yes	Yes
Valley filling	Yes	No	Yes	Yes	Yes
Meeting sudden demands	Yes	Yes	Yes	Yes	Yes
V&F Control	Yes	Yes	Yes	Yes	Yes
Effectiveness to increase penetration	Good	Kind	Better	Better	Good
Controllable loads cost	Low	Low	High	Low	Low

4. Microgrid protection schemes

The two different levels of protection schemes required for microgrid. One is, when the microgrid is operates on grid connected mode and other one is when the microgrid is operates on autonomous mode. The protection issues on the grid connected mode are lag in the response time of circuit breakers at PCC (Point of Common Coupling) or by the false tripping of an isolation devices and the reconnecting speed of the microgrid with utility grid after the fault rectification. Therefore, the protection system must be proactive to the changes happening in the microgrid operations [10]. The different level of microgrid protection schemes which are in the trends discussed as follows,

i) Adaptive Protection: In this protection scheme an intelligent electronic devices (IED) are used as protective relay and it can be configured by several settings which correspond to different operating states of the protection system. Adaptive is an on-line protection scheme where the modification for the preferred relay settings can be done in order to provide the response to the system changes [14]. The tripping characteristics (configurations) of numerical relay are well suited for the practical implementation of an adaptive protection system and the standard communication protocol can create the required coordination among the relays. So that an individual relay can get the communication with microgrid central controller (MGCC) or between different relays. In this method of protection, the relay settings are adopted to various operation status of microgrid and to different operating modes. The following problems are associated with the practical implementation adaptive protection strategies in microgrid [16], [27].

- The establishment of communication infrastructure among the protective relays (IED) and MGCC is very costly.
- There will be complications in short-circuit and fault current calculation with different operating modes of microgrid.
- Possible configuration must be tested before the implementation of a protection strategy by keeping the microgrid in off-line.
- The necessary configuration must be updated with the IED even if it is in the utilization currently.

ii) Differential Protection: In this protection scheme the current transformer and relay are used to ensure the fault in the line by comparing the value of high frequency sampled current which measured at both end of the line. The protection relay will be trip if there is any difference between the samples above the threshold. During the fault nil conditions the return value of the sensors which measured from all the lines and nodes will be zero [28]. By sensing zero and negative sequences of current, this protection method will detect the single phase LL (Line to Line) and LG (Line to Ground) faults in the Microgrid network [24]. As a future microgrid concept, an intelligent relay has been developed to be operated in 50ms time and it will be located at both end of the line to protect the microgrid in both grid connected and autonomous mode of operation. The method of protection by keeping the relay at both end of the feeder will provides robust protection to the microgrid and as a developed strategy the PLC (Power Line Carrier) communication based protection method has been implemented in order to provide protection not only for feeder and also provide the solution to buses and DG sources [44].

iii) Distance protection: This method of protection system has implemented with distance relays which are capable of measuring line impedance (Z) of a length of a feeder to a predetermined point and it has designed with inverse time tripping characteristics to respond only for the faults which are occurred between the relay points and also it has the ability to isolate the faulty in the both modes of microgrid operation [42]. It is important that the communication between distributed generators should be effective for ensuring selectivity and proper clearing of faults [45].

iv) Voltage Protection: In this protection scheme, the output voltage of DG sources are measured then converted as DC quantity by d-q reference frame to protect the microgrid against Zone-in and Out-of-Zone faults. The protection method of this scheme does not depend on communication system which deployed in the network using pilot wires, optical fibers or Ethernet and the salient feature of this one is adoptable for various configurations of microgrids [24, 28]. To protect microgrid in both grid connected and autonomous mode of operations, a new protection method based on busbar voltage analysis and the direction of faults has discussed in [46], the author designed relay hardware/software using IPCs (Industrial Personal Computers).

Table 2: Comparison of Microgrid Protection Schemes [24 – 28, 37 – 44].

Protection Scheme	Relay Used	Operation Mode	DG Type	Comm. Link	Merits	Demerits
Adaptive	Directional OC Relay	Islanded	Inverter based	Yes	- Fast protection in all operating modes.	- Applicable for islanded mode of operation only.
Differential current	Digital Relay	Grid connected, Islanded	Rotating and Inverter based	Yes	- Ability to detect high 'Z' fault.	- High implementation cost.
Distance	Distance Relay	Grid connected, Islanded	Inverter based	No	- Zone protection is depends on the 'Z' of lines.	- Unnecessary relay tripping for the ground faults if the star connected load downstream to the fault.
Over current	OC Relay	Grid Connected	Rotating and Inverter based	No	- No changes require on existing protection relay.	- Not suitable for islanded mode.
Symmetrical current	OC Relay	Islanded	Inverter based	No	- Providing effective protection for LL and SLG faults.	- Single phase tripping not allowed, Three phase faults not considered.
Voltage	-	Islanded	Inverter based	Yes	- Separate protection for Generators.	- Single phase and high 'Z' faults not considered.
Harmonics	-	Islanded	Inverter based	Yes	-	- Trip to fail if more dynamic loads in the network.
Current travelling waves	-	Grid connected	-	No	- Independent from high fault current and power flow direction.	- No simulation work has conducted.

5. Communication techniques

The reliable and scalable communication network is required for monitoring power lines in real time to protect the power systems from natural disasters. Mainly, it provides the facility to service providers in order to access electricity usage data remotely. PLC (Power Line Carrier), DSL (Digital Subscriber Line) and Fiber optical, these are the available broadband technologies which employed between control center and smart meters [73]. PLC is a well suited cost effective medium for the utility when the distributed feeders are considered and it can transmit the data at maximum rate of 11kbps only at (9-95) KHz narrow frequency. This rate of communication may not enough to support applications where large amount of data to be transferred. Newly developed power system network could be implemented with fiber optic network very close to feeders, thus enable the communication infrastructure for both utility and consumers [77]. PSTN (Public Switched Telephone Network) is another wired option which provides simple, highly reliable and inexpensive solution with bi-directional communication, but it is limited by the bandwidth which offered. So that the developed countries moving away from PSTN to wireless technologies. The feasibility of this technology is leading the communication without any physical connection between numbers of nodes. As a wireless communication technology the HAN (Home Area Network), NAN (Neighborhood Area Network) and WAN (Wide Area Network) are playing major role in monitor and control the operation of the Grid at distributed level [80], [81].

Home Area Network (HAN): Home appliances which needed to be automated are connected at HAN level. In the case of SG (Smart Grid), HAN is the lower level communication network of the overall infrastructure, for example connecting smart meters and control devices for integrating DGs to microgrid, plug in hybrid electric vehicle and to implement DR applications. Its coverage range is limited to ten meters only.

Neighborhood Area network (NAN): This network acting as gateway between HAN and upper level communication devices and frequently its transmitting the data information between customers, delivered from different HANs and aggregation points. Therefore the range of NAN network is around thousands of meters and particularly this range of communication is well suitable for medium size electrical grid (MG).

Wide Area network (WAN): WAN is the backbone for smart microgrid network and the main task of this network is transmitting all the collected data information to grid operator and commanding the consumers. Thus WAN must be abled to handle and carry larger amount of data information to wide range.

HAN and NAN levels communication networks includes the low power wireless technologies such as Bluetooth, ZigBee, and Wifi etc. The physical layer of Bluetooth technology is defined by IEEE 802.15.1 standard and it has designed to be operating on personal area networks (PANs), the coverage of this technology is 10m only but it can be extended to 100m by adding repeaters and increasing the data rates about 720kbps. In HAN network this protocol providing greatest solutions to interface smart meters to customer devices [76]. The physical layer of ZigBee protocol is defined by IEEE 802.15.4 standard and it is well adopted for framing mesh network and low duty cycle applications, without any repeaters this can cover the range of 100m for the data rate about 250kbps. This technology using ISM frequency bands such as 868 MHz, 915 MHz and 2.4GHz for data transmission and it is considering as one of the suitable technology for networking the devices in HANs [84], [85]. Wifi is the cost effective, high data rate communication protocol which defined by IEEE 802.11 standards, the characteristics of Wifi make attractive communication for NAN networks. Coverage of the Wifi is around 200m and the high power consumption only considered as its drawback [79]. Table 3 shows the comparison statements of wireless technologies. Controllers analysis for non-linear system has been reported [96-108].

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Table 3: Comparison of Wireless Communication Technologies [73 – 85]

Microgrid Network level	Technology	Frequency Band	Data Rate	Range	Power Consumption
HAN	Bluetooth	2.4 GHz	720 kbps	10 m	Classical: 100mW Low energy: 10mW
	ZigBee	868 MHz/915 MHz	250 kbps	100 m	10mW
HAN and NAN	WiFi	2.4 GHz	Up to few Gbps	200 m	1.5W
	M2M Solutions	ISM Band	Up to 100 kbps	From 200m to tens of km	50mW

6. Conclusion

This paper has surveyed the key concepts which concerning electrical microgrids and protection schemes, load managements, and wireless networks in order to transform a classical small scale grid into a smart microgrid. Microgrids (MGs) are the paradigm of the new smart electrical grid (SGs) that includes effective management and control strategies, penetration of renewable energy resources, energy storages, and power unbalance risk. In order to assure an intelligent operation for a microgrid, it is necessary to be implement with an effective protection schemes, well coordinated communication between LC, SC, MGCC and grid operator by deploying smart sensors and actuators in the distributed level network.

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