

STUDY OF MICROGRID AND ITS COMMUNICATION PROTOCOLS

*A Dissertation Submitted in partial fulfillment of the requirement for the award of Degree
of*

**Master of Engineering
in
Power Systems**



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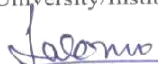
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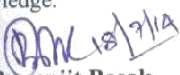
I hereby declare that the work which is being presented in this dissertation entitles as, '**Study of Microgrid and its Communication protocols**' in partial fulfillment of the requirements for the award of degree Master of Power System & Electric Drive submitted in Electrical & Instrumentation Engineering Department of Thapar University ,Patiala, is an authentic record of my own work carried out under the supervision and guidance of **Dr. Prasenjit Basak** ,Assistant Professor ,EIED ,Thapar University.

The matter embodied in this thesis has not been submitted to any other University/Institute for the award of any Degree or Discipline.

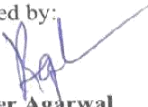
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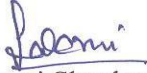

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I would also like to thank my friends who devoted their valuable time and helped me in all possible ways towards successful completion of this work. I thank all those who have contributed directly or indirectly to this work.

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ABSTRACT

The traditional power systems throughout world or mainly dependent upon the conventional method of power generation of electrical power by the combination of Fossil fuel. But there kind of fuel is being exhausted rapidly which will create huge crises fuel for power generation after few decades. So worldwide research activities have already had being initiated to find out the alternatives source of energy through the maximum utilization of renewable energy resources. It is realize that individual capacity of renewable energy resources such as, Photovoltaic Generator, and Wind turbine, etc. are small compared to the traditional generation technology such as thermal power station. In this scenario microgrid system is emerging as a probable solution to solve the power crises in future. The microgrid is interconnected system of different types of energy resources such as photovoltaic, wind energy, Biomass, small hydroelectric generation statics, Fossil fuel etc. which needs proper coordination for satisfactory operation to meet the load demands. To achieve this coordination, microgrid itself requires good communication infrastructures so that it can operate in grid and Islanded mode as well as in the situation while same faults have occurred in the power network.

In the present work a detailed Literature survey has been performed to identify the latest communication infrastructure and communication protocols as suggested by many researchers and IEEE/IEC standards also a sample microgrid is modeled and simulated to investigate the basic mode of the operation, the results represented in the form of waveforms which are found satisfactory.

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1.1 Overview of Microgrid

A microgrid is a small power system composed of one or more distributed generation units that can be operated independently or connected to utility. The micro grid is small scale flexible reliable source of electricity. It is connected to both local generating system units and utility grid to prevent from outages. Microgrid may range in size from a tiny residential load to small city.

As energy generation and distribution companies are competing in the market place, we have seen an increasing interest in renewable or non- conventional energy source. A microgrid is an energy community having clean energy sources such as solar power, wind power, and fuel cells and energy storage devices such as batteries. The energy sources and energy storage devices are distributed in the community, and they are called distributed generation systems (DGs) and distributed energy storage devices (DSs), respectively. Recently, attention on the microgrid has been growing as an eco-friendly power system reducing climate change. There are several reasons why microgrids are increasingly used. First they use alternate energy resources, which are more environmentally friendly commitments and require fewer technical skills to operate as they rely more on automation. Finally, microgrid is the only option if new transmission infrastructure cannot be developed in a timely or cost effective fashion. Alternatively, it can provide high quality, uninterrupted power supply as needed by many companies who use highly sensitive equipment.

The microgrid can be operated by two operation modes: the grid-connected mode and the islanded mode. In the grid-connected mode, a microgrid is connected to a power system, especially a distributed system. On the other hand, the islanded mode means an isolated operation mode from any power system for the case of fault occurrence in the connected power system or geographical isolation such as a small island. In the islanded mode, microgrids should be operated to meet a power balance between supply and demand without power trade. Whenever a power imbalance occurs, the output of DGs is decreased and load shedding is used to solve the power imbalance.

The on-site generation sources give ability to isolate the microgrid from a larger network and provide highly reliable electric power. by product heat from generation sources such as micro turbines could be used for local process heating or space heating and allowing flexible tradeoff between the needs for the electric power and heat. Microgrids may be considered as a solution to 30 and 31 July 2012 blackout in India. This outage affected over 620 million people about 9% of the world population or half of India's population spread across 22 states in Eastern, Northern and Northeast India.

1.2 Role of Communication Method in Microgrid System

For protection and power control in Microgrid communication systems are very important. The basic communication methods so far used in the existing microgrid testbeds are: power-line carrier, broadband over power line, leased telephone line, global system for mobile (GSM) communication, LAN/WAN/Internet (TCP/IP), wireless radio communication, optic fiber, WiFi 802.11b ,WiMAX 802.16 and ZigBee/IEEE 802.15.4 (for automated metering system). These are the method used for communication in Microgrid [1].

1.3 Objectives of the Thesis

- To study the deployment of communication system in microgrid through compressive Literature survey.
- To study the different international Standard of communication as Suggested by IEC/IEEE for Microgrid in the perspective of smart grid Application.
- Modeling and simulation of microgrid working in Grid connected and Islanded Mode.
- To Investigate the scope of communication protocols for the microgrid System which is simulated in the present work.

1.4 Literature Review

[1] **H. Akagi** *et.al* [2004] has presented the work on renewable power plants are implemented in rural areas which are far away from the main grid network and there is possibility of weak transmission line connection. The microgrid concept provides an effective solution for such weak systems. The operation can be smoothened by the hybrid generation technologies while minimizing the disturbances due to intermittent nature of

energy from PV and wind generation .Also there is possibility of the power exchange with the main grid when shortage and excess occurs in the microgrid.

[2] **P. Piagi** *et.al* [2006] has proposed the microgrid concept which acts as solution to the problem of integrating large amount of the micro generation without interrupting the utility network's operation. The microgrid or distribution network subsystem will create less trouble to the utility network than the conventional micro generation if there is proper and intelligent coordination of micro generation and loads. In case of disturbance on the main network microgrid could potentially disconnect and continue to operate individually which helps in improving power quality to the consumer.

[3] **F. Katiraei** *et.al* [2006] has presented the microgrid concept which lowers the cost and improves the reliability of small scale distributed generators. the main purpose of this concept is to accelerate the recognition of the advantages offered by small scale distributed generators like ability to supply waste heat during the time of need. From a grid point of view, microgrid is attractive option as it recognizes that the nation's distribution system is extensive, old and will change will slowly. This concept permits high penetration of distribution generation without requiring redesign of the distribution system itself

[4] **M. Barnes** *et.al* [2007] has summarized and highlighted the operating principles and key conclusion of research and field trials to-date of microgrid. An overview is given on demonstration projects for microgrid which have been and are being constructed. The range of hardware and control options for microgrid operation is reviewed.

[5] **J. Zhenhun** *et.al* [2008] has presented the integration of wind turbines and photovoltaic system with grid leads to grid instability one of the solutions to this problem can be achieved by the implementation of microgrid. Even though there are several advantages associated with microgrid operation there are high transmission line losses. In microgrid there are several units which can be utilized in a house or country. In a house renewable energy resources and storage devices are connected to DC bus with different converter

topology from which DC loads can get power supply. Inverters are implemented for power transformer between AC and DC buses. Common and sensitive loads are connected to AC bus having different coupling points. During fault in the utility grid microgrid operates in island mode. If in any case renewable source can't supply enough power and state of charge of storage devices are low microgrid disconnect common loads and supply power to the sensitive loads.

[6] **C.V. Dobariya** *et.al* [2010] has followed the centered around the encountered and foreseen issue, enabling technologies and economics for encouraging and deployment of microgrids in India. it is also presents state of the art issue and feasible solution associated with the deployment of microgrid technologies leading to the conceptualization of efficient and smart microgrids. The role of enabling technologies, automation and communication for sustainable development of microgrids is also explained.

[7] **T.E. Del Carpio Huayllas** *et.al* [2010] has presented the current status and state- of-the – art of microgrid systems as well as the barriers that are being encountered for their integration to the network. The expectation about the microgrid performance, issues related to the microgrid standards, autonomous operation, control strategies, regulatory barriers as well as its protection and islanding operation, among other aspects, were discussed. Some examples of practical installation worldwide will also be presented.

[8] **S.S.Venkata** *et.al* [2010] has presented a digital relay scheme with communication. Also proposed a microgrid with customer owned distributed generation (DG) sources. In traditional microgrid protection scheme will not work successfully so solve this problem for protection scheme using digital relays with communication network. The protection system relies primarily on the differential protection based on the sampling the current waveform at 16 samples per cycle or more. They presented ,the improves reliability can be obtained with the central controller with communication to multiple measurement units for a reduced cost without installing explicit relays at each end of every line. The

strategy for the number of relays and their location can be evaluated based on the network topology at the location and rating of the DG sources.

- [9] **Alfredo Vaccaro** *et.al* [2011] has proposed an advanced web services which is based frame work for integrated microgrid control, modeling, and monitoring. The core component presented framework is the microgrid engine which is responsible for the execution of the microgrid management function in a distributed scenario. It is also includes a network of remotely controlled units distributed in the most critical microgrid section for field data acqustion and advanced protective functionalities. They also proposed three kinds of web services GISinterfaceWS, DataAcquisitionWS, Eassessment WS. Web service based frame work has been deployed on a computational grid.
- [10] **Taha Selim Ustun** *et.al* [2011] has proposed about the microgrid protection system with central protection Unit. Microgrid in order to handle the impacts of distributed generators and make the conventional grids for large scale deployment of distribution generation. They presented protection scheme for microgrids with high DG penetration. They proposed the system considers two events as like interruption one of is microgrid connection or disconnection from the grid and DG connection or disconnection from the microgrid. Here central controller is used for all operating point calculation. All measurement ant the set points recived from the central unit and this make system more robust so no need continuous communication is the decision making process.
- [11] **Giuseppe Stanciu** *et.al* [2011] has presented the review of the requirements for the end –to-end communication system as the backbone for command and control this within smart microgrids. Here communication technologies used for BCIT smart Microgrid. WiMAX network regarded as a good candidate for WAN in the smart grid. ZigBee and Wi Fi networks can coexist. ZigBee network is deployed in large scale as LAN.
- [12] **Alexis K wasinski** *et.al* [2012] has presented two main cases for the analysis: a forced operation is islanded mode caused by an extensive power grid outage and a preferred

operation separately from the grid due to the design centre. Explored power alternatives for communication sites where there is no grid connection. Second part discussed about availability models for sources and lifelines because they heavily influence the operation of micro grids when no main grid is not present. Three models are commented named is renewable energy sources, sources that require continuous fuel supply and sources with discontinues fuel supply that is stored locally.

- [13] **Tine L. Vandoorn** *et.al* [2012] discussed the interaction between secondary microgrid control and a primary control strategy which is based on the voltage droops and constant –power band used with a width which is depended on the nature on the energy source. The secondary and primary control strategies are based on the linkage between the grid voltage and active power, take into account optimizes integration of renewable energy source by wide constant power band is used
- [14] **S.Mishra** *et.al* [2012] discussed the isolated microgrid comprising both controllable and uncontrollable source like diesel, wind, solar, generator, fuel cell, hydrogen storage and battery is considered. They used a central controller which takes the decision based on the status of the loads and sources. The status is obtained through multi agent concept and also through internet used User Datagram Protocol/Internet Protocol. The all decision is transmitted to the central control sources to regulate the power output from the battery only during transient and resulting in floating battery scheme in a steady scheme.
- [15] **J. Frolik** *et.al* [2012] has presented a robust communication control strategy for load, source and storage agents in a microgrid. The work is motivated by low inertia microgrid environment having high penetration of renewable resources and this is ones where high data rate communication is require to mention the power stability. They proposed multistate automation based approach which is assigned communication priorities in relation to the agents power on the microgrid. They adapted automation based which is developed for the wireless sensor network control to the problem of MAC for microgrid communication.

- [16] **James Weimer** *et.al* [2012] has proposed the recent communication technologies used for microgrid. Testing smart grid information and communication infrastructure is imperative to ensure that they meet the industry requirements and standards and also do not compromise the reliability. They required indentify and testing communication infrastructure for communication between the distributed energy resources, substation, building, etc. Mainly this work they introduce in the Virtual microgrid laboratory and also provided a preliminary analysis of Long-Term Evolution as a microgrid communication infrastructure.
- [17] **M. Amin Zamani** *et.al* [2012] has proposed a communication assisted protection strategy implemented by the commercially available microgrid processor based relays for the protection of medium voltage microgrids also through the developed protection strategy from communication. It offers the backup for, manage the communication network failures. They proposed the different fault scenario in the PSCAD software environment
- [18] **Yixin Zhu** *et.al* [2012] has presented a new communication platform for the microgrid which works under the master – slave strategy .according to the different information content and different communication time demands they used multiple communication protocol to meet the demand. They transmit status information for display by Ethernet and transmit the control information which took the little information but required real time performance by CAN bus, Data Acquisition and the instruction operation all are done in microgrid using communication protocols.
- [19] **Massimo Gallina** *et.al* [2012] has proposed a synchronization protocol which is based upon the Network Time Protocol. This protocol is implemented at the MAC layer. By used of the very light message exchange every 10s, it assures a synchronization error below 10us .they tested a synchronization algorithm via PLC for smart microgrid application. For this they used NTP protocol.

- [20] **Alessandro Giusti et.al [2012]** Controllers simultaneously optimizes two possibly conflicting objectives: minimization of energy costs for the end user (considering a known, time dependent tariff) and stabilization of the collective load profile (load flattening). The former objective can be optimized separately by each controller. On the other hand, the latter could benefit from a communication infrastructure that allows the controllers to clearly exchange information and coordinate. We study how different levels of communication pervasiveness affect system show; we developed a realistic micro-simulation environment accounting for the behavior of residents, dispatchable and non dispatchable household loads, and the effects on the distribution network. We consider a generic model of communication among household controllers, not tied to any specific technology, and based on the partitioning of the households in a number of groups (neighborhoods). Controllers within the same neighborhood enjoy full connectivity, but cannot interact with controllers outside of their neighborhood. Through extensive simulation experiments, we observed that even communication neighborhoods constitute by as few as 3, 4 households are enough to effectively stabilize the total network load profile, with minimal bandwidth use. Increasing the neighborhood size leads to comparatively negligible performance improvements. We terminate that effective load flattening can be achieved with minimal requirements of communication infrastructure and transmit information
- [21] **Taha Selim Ustun et.al [2012]** has presented one embodiment of a protection system which employs a micro-grid central protection unit (MCPU) to coordinate differential current protection. Recently Micro grid concept has been planned where the networks are divided into smaller manageable sets which can be more effectively and efficiently operated. This concept allows conventional grids to be made appropriate for large scale deployments of distributed generation. The dynamic structures of micro-grids change very often depending on various network factors. This dynamic behavior of micro-grids to alter act under a variety of network conditions is an area that needs to be more thoroughly investigate and understood in moving forward with the integration of the micro-grid concept to existing power supply grids. The communication infrastructure of the proposed protection system has been modeled according to IEC 61850 international

communication standard for power networks as well as its recent extension for distributed generators (DGs) IEC 61850-7-420. The system is implemented in Matlab/Simulink.

- [22] **Jairo Giraldo** et.al [2013] Motivated by the increasing interest in networked multi-agent systems and the wide number of applications in distributed control of smart grids, we address the problem of synchronization of microgrids. Two topologies are considered: the physical topology that relates the interconnection of distributed generators and loads, and the communication topology, which describes the information flow of the power system measurements. They proposed a control strategy based on the information flow and we show that there exists a strong relationship between both topologies in order to achieve synchronization. As a matter of fact, we show that our results can be extended when isolated group of nodes are taken into account, and they can be connected or disconnected to the main grid. Finally, the effects of time-varying sampling are analyzed using some average passivity conditions, and sampling-time independence is demonstrated with the proposed controller.
- [23] **Rukun Mao** *et.al* [2013] has proposed here a microgrid with wireless communication links for microgrid control has been intended and developed. The complete simulation model has been developed in MatLab SimuLink with faultless integration of the power subsystem and the communication subsystem. Unlike the predictable co simulators that usually connect two existing simulators together by create an interface, which has a steep learning curve, the proposed simulator is a compact single unit model. Thorough modeling of the power subsystem and communication system is presented as well as the microgrid control architecture and strategy. The impact of different communication system performance on microgrid control has been studied and evaluate in the proposed simulator. The results help recognize the cost effective communication solutions for microgrid applications.
- [24] **Lijun Qin** *et.al* [2013] has proposed a reliable carrier communication scheme design in intelligent microgrid to establish a reliable, economical and practical smart micro-grid is

a trend for power system automation technology. In order to improve the efficiency of communication, a good communication protocol is also to be considered.

- [25] **Mohamed A. Ahmed** *et.al* [2013] here discussed a microgrid will have the ability to generate their own energy requirements locally through renewable energy systems such as photovoltaic (PV) and wind turbines (WT). they presents the communication network architectures using both wireless and dedicated wired medium for monitoring and controlling the distributed energy systems (DES) including a small scale WT and PV system. To watch the condition of standalone system (PV and WT), the various types of sensors are used to assemble different measurement data. The data transmission rate of each sensor is compute according to the sampling frequency. For DES in grid linked mode, the communication network of microgrid system is configured by hybrid architecture (wired-wireless). Based on network topology and different network configuration, OPNET modeler is used to evaluate the performance in view of total end-to-end delay using three different technologies; Ethernet based, Wi-Fi-based and Zig Bee based architectures.
- [26] **Salman Safdar** *et.al* [2013] has proposed a micro-grid is a small scale power supply network that is intended to provide electricity to a small community with its own renewable energy sources. Due to distributed generation variability, security and load sharing issues, an efficient communication infrastructure is required between its agents (load, generation and storage units). Numerous research efforts are being developed to come up with such communication techniques that can overcome the barriers to apply the concept of micro-grids. They covers the features, characteristics and challenges of microgrids and their associated communication techniques.
- [27] **Wanxing Sheng** *et.al* [2014] here discussed about power line carrier communication technology which is based on a decentralized multi agent system (DMAS), frequency control strategy is projected and investigate in this study on an autonomous micro grid

with communication constraint, where each agent can only communicate with its adjacent agents. Using the optimized average consensus algorithm, the global information can be accurately shared in a decentralized way. Depending on the discovered global information, the cooperative frequency control strategy, which involves primary and secondary frequency manage and multistage load shedding, is executed to achieve a cooperative frequency recovery. Simulation results indicate that the planned frequency control approach can guarantee the consensus and organization of the distributed agents and maintain the frequency stability of islanded microgrids even in emergency conditions.

1.5 Organization of Thesis

The thesis is organized as mentioned below:

A review of the microgrid architecture including configuration, stratum etc are presented in chapter 2. Communication protocols used for microgrid system is identified and discussed in chapter 3. Modeling and simulation of microgrid is presented in chapter 4. The conclusion and future scope of research are presented in chapter 5.

2 OVERVIEW

The microgrid concept has been introduced. A microgrid is a collection of loads and microgenerators along with some local storage and performs just like a model-citizen from grid side thanks to intelligent control. Although a microgrid is itself composed of many generators and loads, it appears as a net load or a net generator to the broader grid with well-behaved characteristics. The motivation behind using microgrids is to divide the enormous conventional utility network into smaller and more easily operable grids [.28]

These smaller electrical networks will manage distributed generators, loads, and storage and protection devices in their own grid. Provided that each microgrid is operating as a model citizen, i.e. either as a load receiving power or as a power supply supplying power with stable voltage and frequency, then the overall utility grid can be operated properly. It is a well-known fact that higher penetration levels of DGs, especially those that require Power Electronics (PE) interface, alter the grid structure and jeopardize safe and reliable operation [29].

The microgrid concept is introduced to manage these generators in smaller quantities rather than trying to tackle the whole network in a holistic manner. In this way, more DGs can be employed in the grid and side-effects on the grid operation can be eliminated[28]. However, there are technical challenges regarding microgrids and their full integration into existing grids such as control, management and protection.

Especially the conventional protection schemes totally collapse since two fundamentals of traditional utility grids, which are the “radial” structure of the grid and passive transmission and distribution networks, do not hold anymore. Instead of making small amendments in these protection systems that are no longer applicable, revolutionary changes are required for safe operation .Microgrids are a technological modernization and business model response to fundamental technical inefficiencies, economic constraints, environmental costs, and brittleness in the electrical grid.

Microgrids are a sustainable technology for attained energy security and more energy independence through energy efficiency, on-site generation and energy management.

The application of being distributed energy resources as microgeneration can cause problems such as local voltage rise, and transformers, islanding and have high capital cost. microgrid can be a better result for these problems. In a microgrid system, the DERs must be equipped with proper power electronic interfaces and control to ensure the flexibility to operate as a single aggregated system keep the power quality and energy output. From the grid point of view, the main benefit of a microgrid is that it is treated as a controlled entity within the power system which can activate as a single load. From customer's point of view microgrids are beneficial because they can meet their electrical and heat requirement locally, supply uninterruptible power, improve power quality (PQ), reduce feeder loss, and provide voltage support. Furthermore microgrids can reduce environmental pollution and global warming by utilizing low-carbon technology [28].

2.1 Architecture of Microgrid

The basic architecture of a microgrid system is presented in Figure 1, which shows that a microgrid system usually consists of distributed generation (DG) resource, storage systems, distribution systems, and communication and control systems.

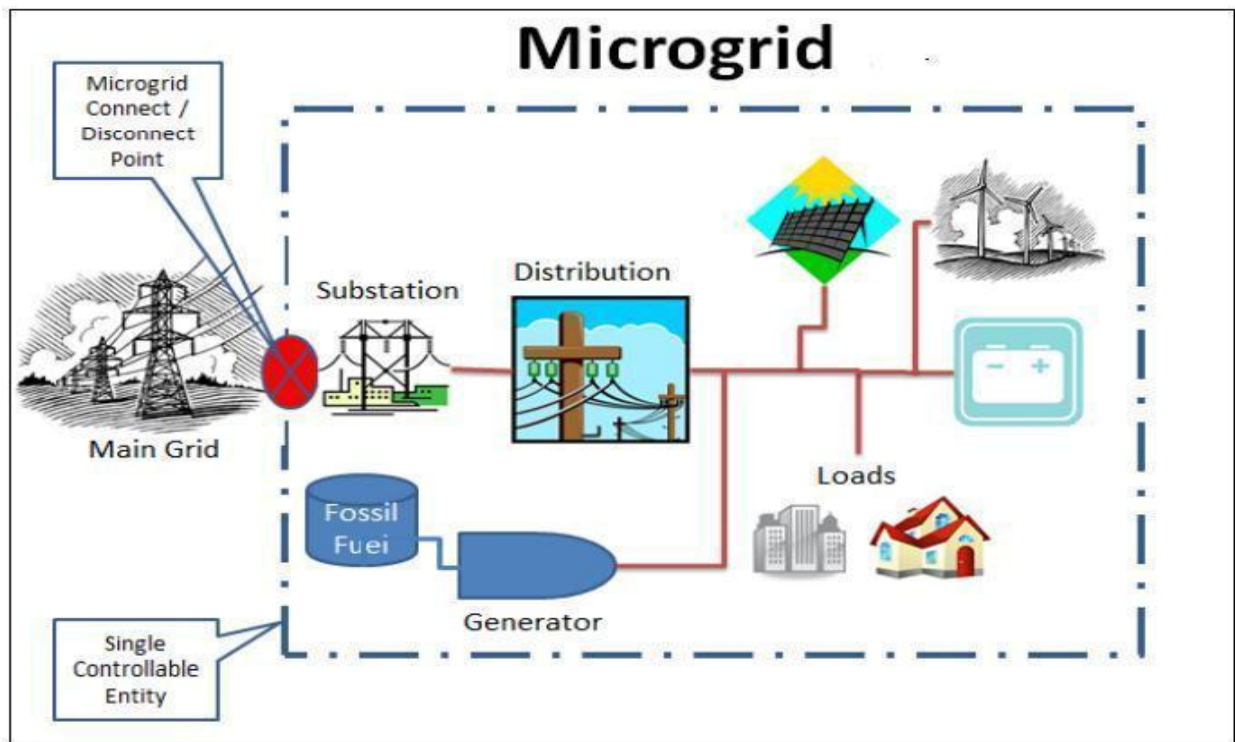


Figure 1: Microgrid Architecture [28]

2.2 Types of Microgrid

Five Types of categories Microgrid given below:-

2.2.1 Community/Utility Microgrids

- Europe leads this segment; however, these deployments do not meet the characteristic definition of a Microgrid because they do not “island.”

2.2.2 Campus Environment/Institutional Microgrids

- The focus of campus microgrids is aggregating existing on-site generation with multiple Loads that is co-located in a campus or institutional setting (e.g., industrial park). Pike Research has experimental that the reason why this particular segment has achieved the Greatest traction in the microgrid market is that a single owner of both generation and Multiple loads all located within a tight geography is easier for the owner to manage Avoids many of the regulatory obstacles noted in other Microgrid segments [29].
- Scale ranges from 4 Megawatts (MW) to more than 40 MW

2.2.3 Military Base Microgrids

- These Microgrids are being actively deploy with focus on both physical and cyber security for military services in order to assure reliable power without relying on the Macrogrid. This segment also includes mobile Military microgrids for forward operating Bases in such places as Afghanistan [29].
- The U.S. Department of Defense (DOD) is actively implementing this approach which is discussed later.

2.2.4 Remote “Off-grid” Microgrids

- These Microgrids never connect to the Macrogrid and in its place operate in an island mode at all times. Examples of this type of Microgrid includes the remote village power systems on islands that usually contain diesels – or wind generation as in Nome, that are interconnected and provide power to the local geography [29].

BC Hydro is working on a project in Bella Coola, British Columbia where an off-grid Microgrid is being developed with the goal of reducing diesel fuel by put together solar photovoltaics (PV), distributed wind, and/or run-of-the river hydropower[29,31].

- According to Pike Research this category correspond to the largest number of current deployments of all Microgrids; however, village power systems represent the lowest average capacity.

2.2.5 Commercial and Industrial (C&I) Microgrids

- These types of Microgrids are maturing quickly in North America and Asia Pacific; however, the lack of well –known standards for these types of Microgrids limits them globally. Therefore they are a “type” of Microgrid but without clear characteristics.

2.3 Distributed Generators

Distributed generation technologies applicable for microgrid may contain emerging technologies such as-wind turbine, solar PV, micro-hydropower, diesel, and some entrenched technologies like single-phase and three-phase induction generators, synchronous generators driven by IC engines. Combined heat and power acts as a total system when heating is also used with electricity[29].

Different kinds of sources are being used in collective heat and power systems such as micro turbines like generally driven by natural gas, hydrogen, and biogas, Stirling engines, and IC engines. Collective heat and power system allows optimum usage of energy by capturing the excess heat, thereby achieving efficiency values of more than 80%, compared to that of about 35% for conventional power plants. Some typical characteristics of commonly used DG sources are shown in table 1 [30].

Table 1 : Typical characteristics of common DG sources [30]

Characteristics	Solar	Wind	Microhydro	Diesal	Chp
Availability	Geographical Location dependent	Geographical Location dependent	Geographical Location dependent	Any Time	Dependent on Source
Output Power	DC	AC	AC	AC	AC
GHG	None	None	None	High	Dependent on source
Control	Uncontrollable	Uncontrollable	Uncontrollable	controllable	Dependent on source
Typical interface	Power electronic converter	Power electronic converter	Synchronous or induction generator	none	Synchronous generator
Powerflow contol	MPPT & DC Link voltage cont	MPPT ,Pitch torque control	controllable	controllable	AVR end governor

2.4 Microgrid system with PhotoVoltic Generator

Solar PV generation involves the generation of electricity from solar energy. Due to huge improvement in inverter technologies [31], PV generation is now preferred worldwide as Distributed Energy Resources (DERs). The major advantages of a PV system are [31]

- The sustainable nature of solar energy.
- Positive environmental impact,
- Longer life time and silent operation.

Although photovoltaic (PV) cells can be effectively used as DERs in Microgrid systems, they have some disadvantages including.

- High installation cost,
- low energy efficiency,
- Restriction to certain locations and weather dependence.

It has been reported that small PV installations are more cost valuable than the larger ones. As the nature of PV generation is DC power, a suitable type of power converter must be working to convert the DC voltage to AC voltage. As shown in figure 2 some applications of PV system are [31].

- Space programs,
- Remote locations where grid electricity is difficult to get,
- Lighting road signs and road light,
- roof projects for home lighting and heating.

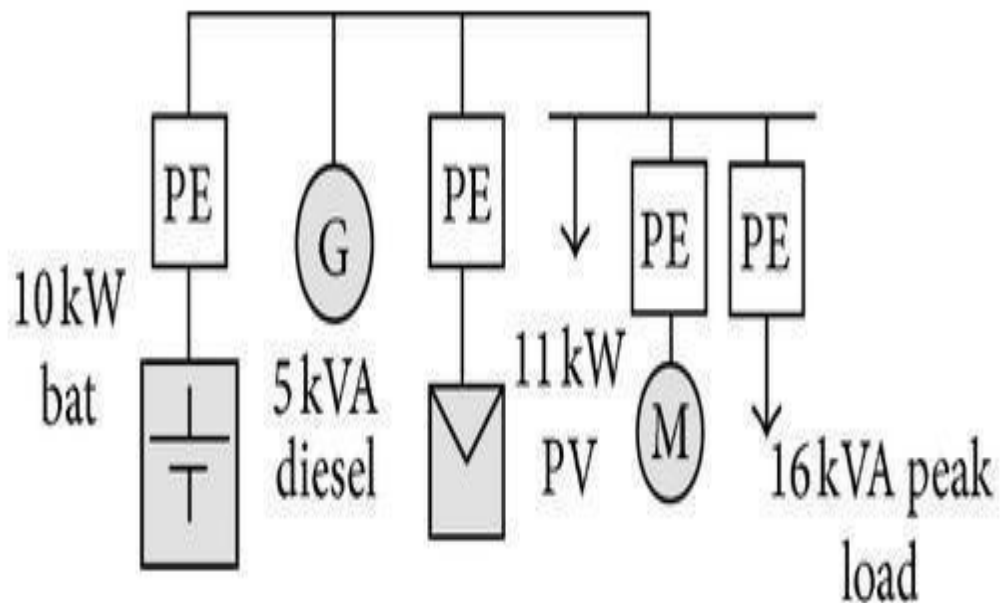


Figure 2: Microgrid with photovoltaic [31]

2.5 Wind Energy

Wind turbine converts wind energy into electrical energy using the wind energy conversion systems (WECSs). Wind energy has been popular for decades. Usually induction generators are used in WECSs. The main part of the wind turbine is the tower, the rotor, and the nacelle. The nacelle accommodates the mechanical transmission and the generator [32] as shown in figure 3.

Wind turbine captures the kinetic energy of wind flow through rotor blades and transfers the energy to the induction generator through the gearbox. The generator shaft is driven by the wind turbine to generate electric power. Wind turbines may have horizontal axis or vertical axis configuration. The average commercial turbine size was 300 kW until the mid 1990s, but recently machines of larger capacity, up to 5 MW and more, have been developed and installed [31].

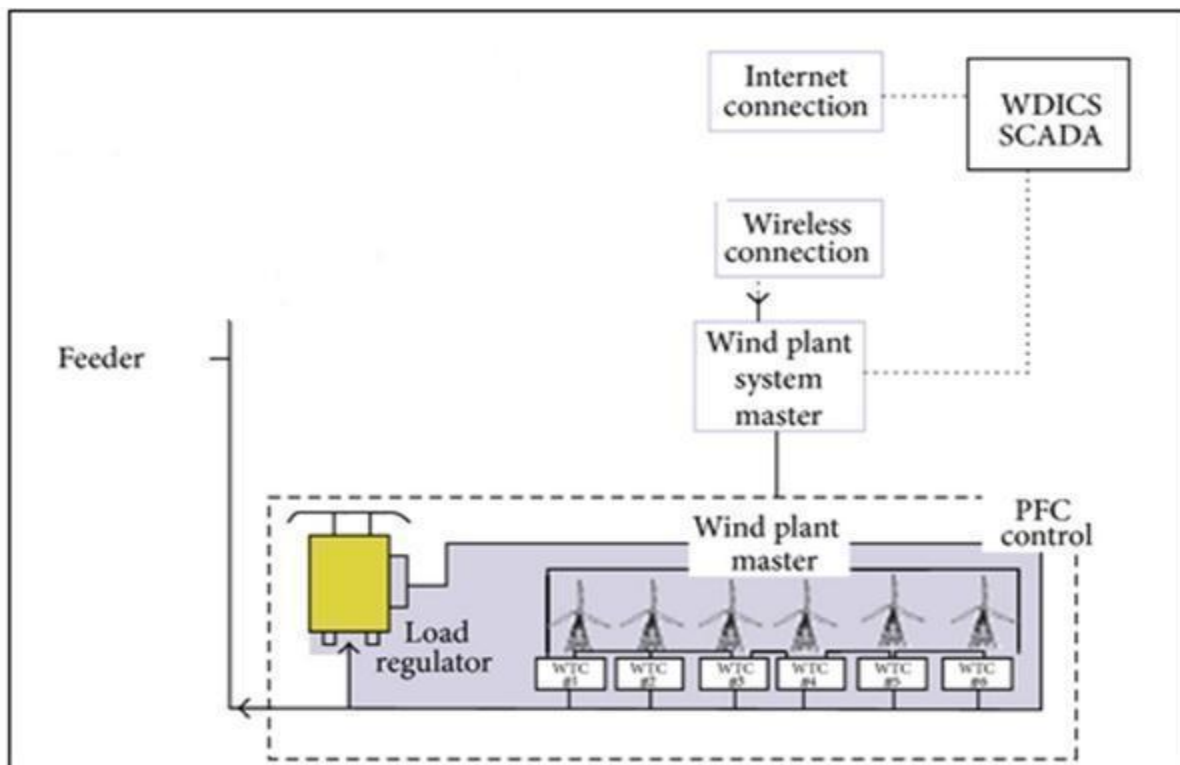


Figure 3: Microgrid System With Wind Energy [33]

2.6 DC Microgrid System

As most of the DERs generate DC power and the DC distribution system has no power quality problems, research on DC Microgrid system is getting importance. But most of the loads are operated in AC system; hence, DC distribution system may not be popular yet. Figure 4 shows a DC Microgrid system[34]. As shown in figure 4.

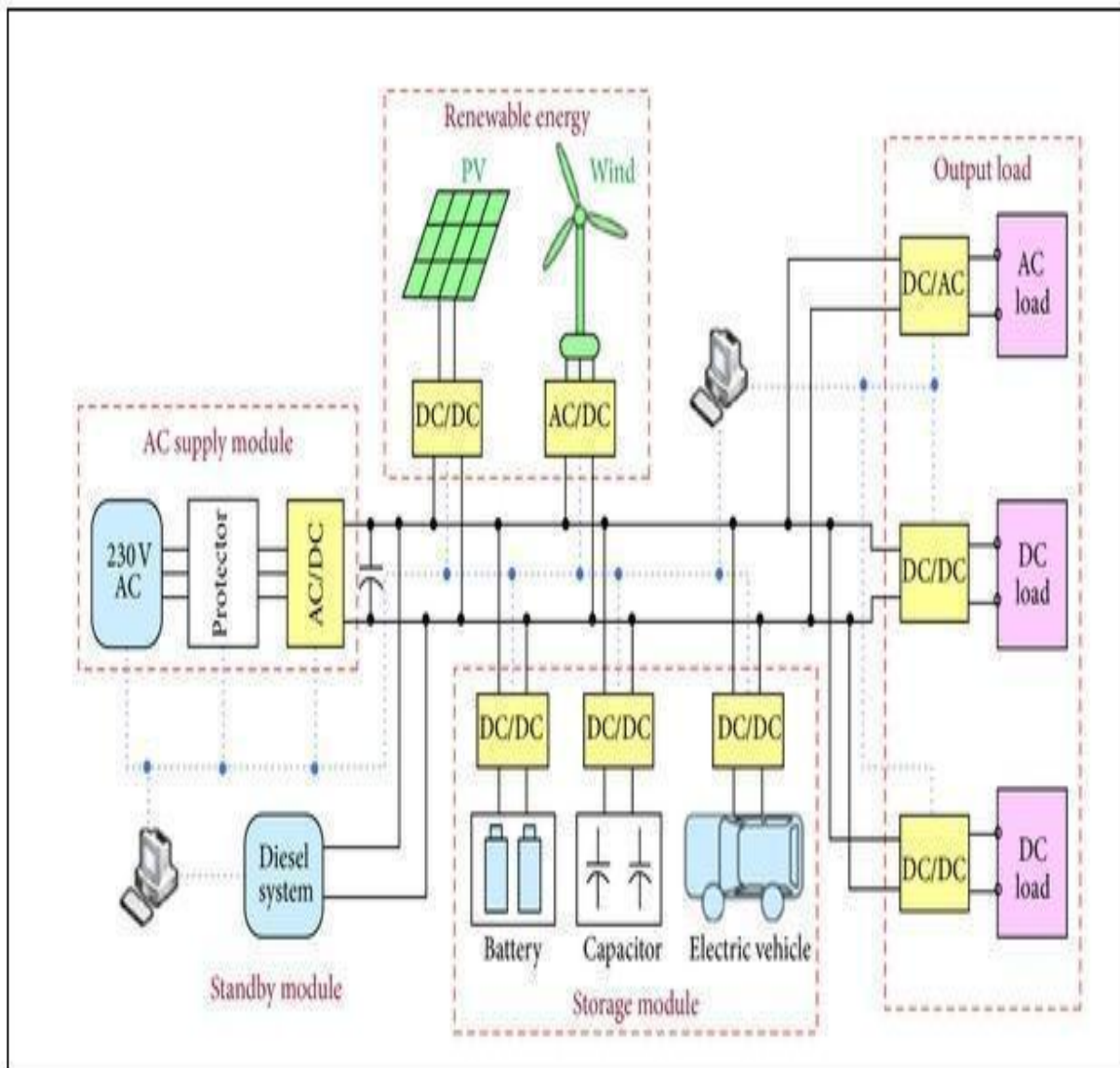


Figure 4: DC Microgrid System [33]

2.7 AC Microgrid system

Microgrids are generally line frequency microgrids. The DERs are connected in a common bus in the microgrid. The DC current from DERs is transformed to 50 Hz AC by a suitable inverter and then transmitted to the load side. Figure shows an AC μ G system. As shown in figure 5.

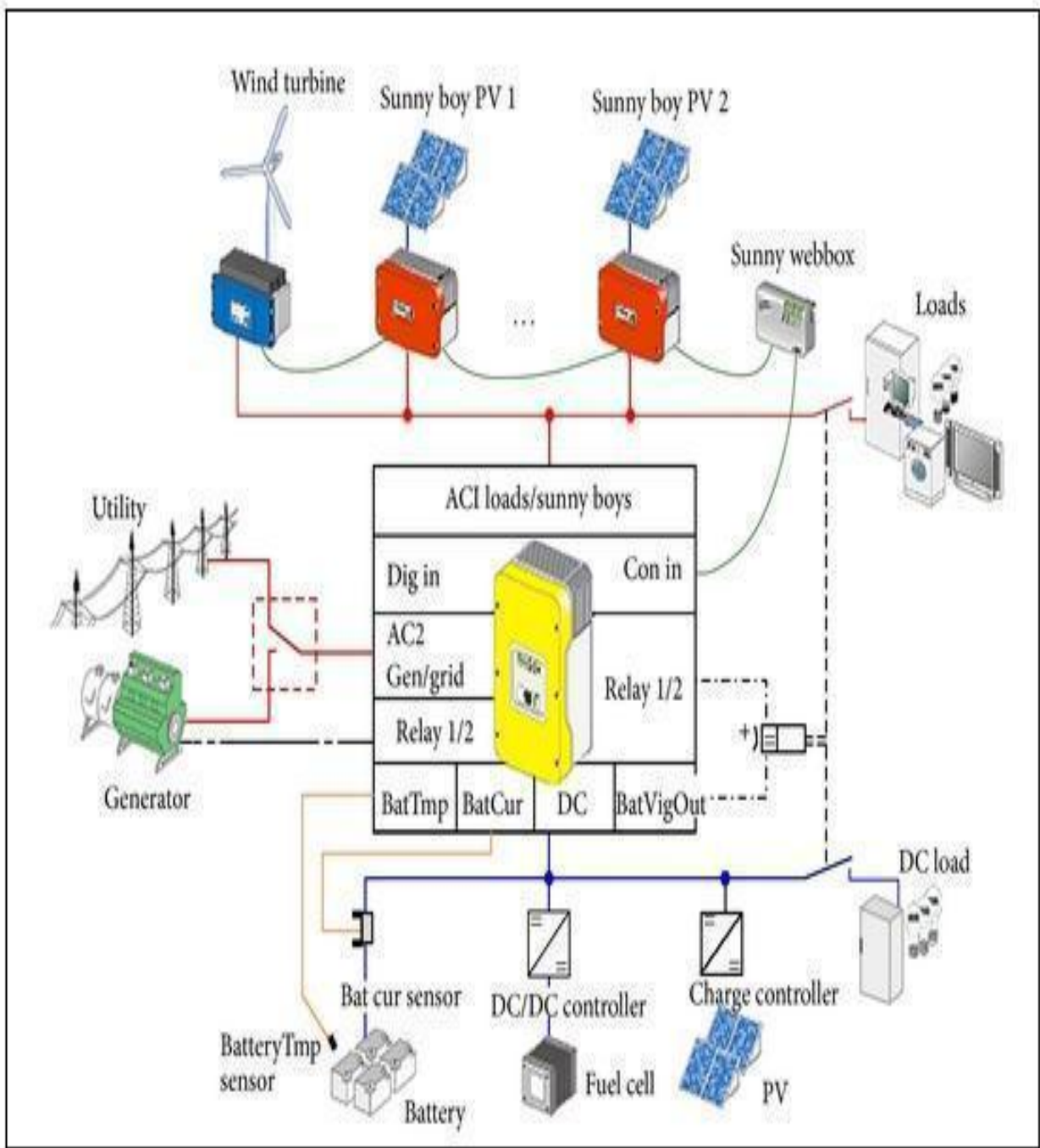


Figure 5: AC Microgrid System [33]

2.8 Advantage of Microgrid System

- A major advantage of a microgrid is its ability, during a utility grid disturbance, to separate and isolate itself from the utility seamlessly with little or no disruption to the loads within the microgrid.
- In peak load it prevents utility grid failure by reducing the load on the grid.
- Significant environmental benefits made possible by the use of low or zero emission generators.
- The use of both electricity and heat permitted by the close proximity of the generator to the user there by increasing the overall energy effectiveness.
- Microgrid can act it mitigate the electricity costs to its users by generating some or all of its electricity needs.

CHAPTER 3 STUDY OF COMMUNICATION PROTOCOLS USED IN MICROGRID SYSTEM

3 Communication protocol

A microgrid system based on the IEC 61850 protocol. It consists of a microgrid monitoring system, a protocol converter that transforms serial data to IEC 61850 data and distributed energy Resource controllers for varied distributed energy resources nodes. The IEC 61850 has been adopted as an international communication protocol to monitor, control, and measure power utilities. The IEC 61850-7-420 has been chosen to interact with the micro grid [34].

Distributed energy resources vendors need communication capability because they interconnect to the smart grid. DER vendors have used their own proprietary communication protocols due to the be short of standards. The distributed energy resources logical nodes data model for DER are standardized under the basic communication structure fixed in the communication networks and systems for power helpfulness automation introduced in the IEC 61850-7- 420 [35]. The IEC 61850 is known as flexible and future-proof due to its capability for decoupling domain-specific application data model from the communication protocol stack.

3.1 MicroGrid System Based IEC 61850

DER nodes, i.e., wind power generator, photovoltaic system, fuel cells, and energy storage are shown in figure 6 that have dedicated controllers for each DER unit. Each controller sends measured and status data that are encoded with their own proprietary protocol to the dedicated gateway using a serial communication link [34].

The gateways convert received measured values and status information to those prescribed by the IEC 61850 data model and send them to the micro grid monitoring system through a 100 Mbps. Ethernet interface using services defined in IEC 61850 [34]. The micro grid monitoring system works as a small Energy Management System (EMS), which sends control command to the DER controller via the gateway as required. Each component of the deployed micro system is described in a top-down manner.

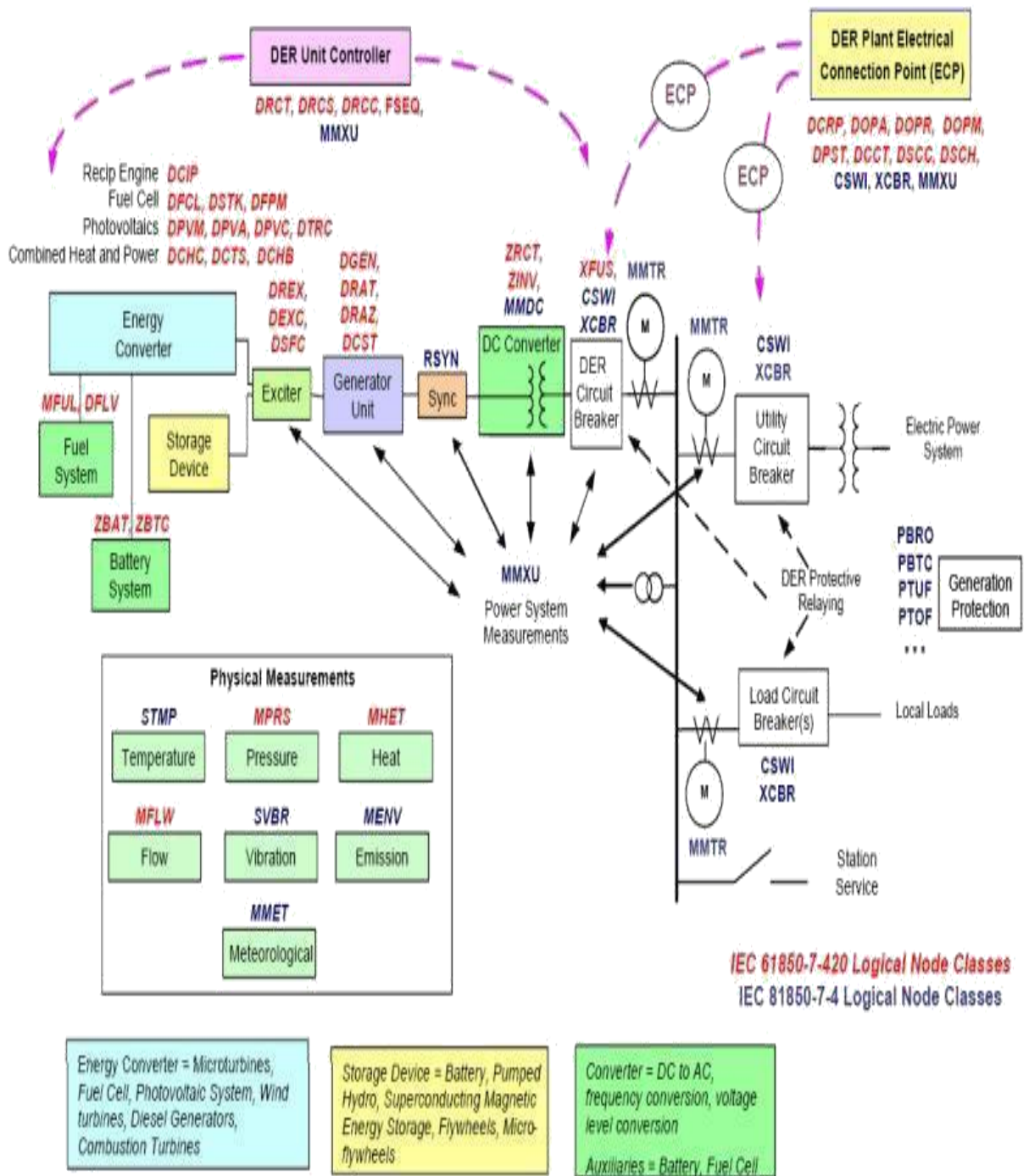


Figure 6: Communication Architecture of the IEC 61850-based Micro Grid System [34]

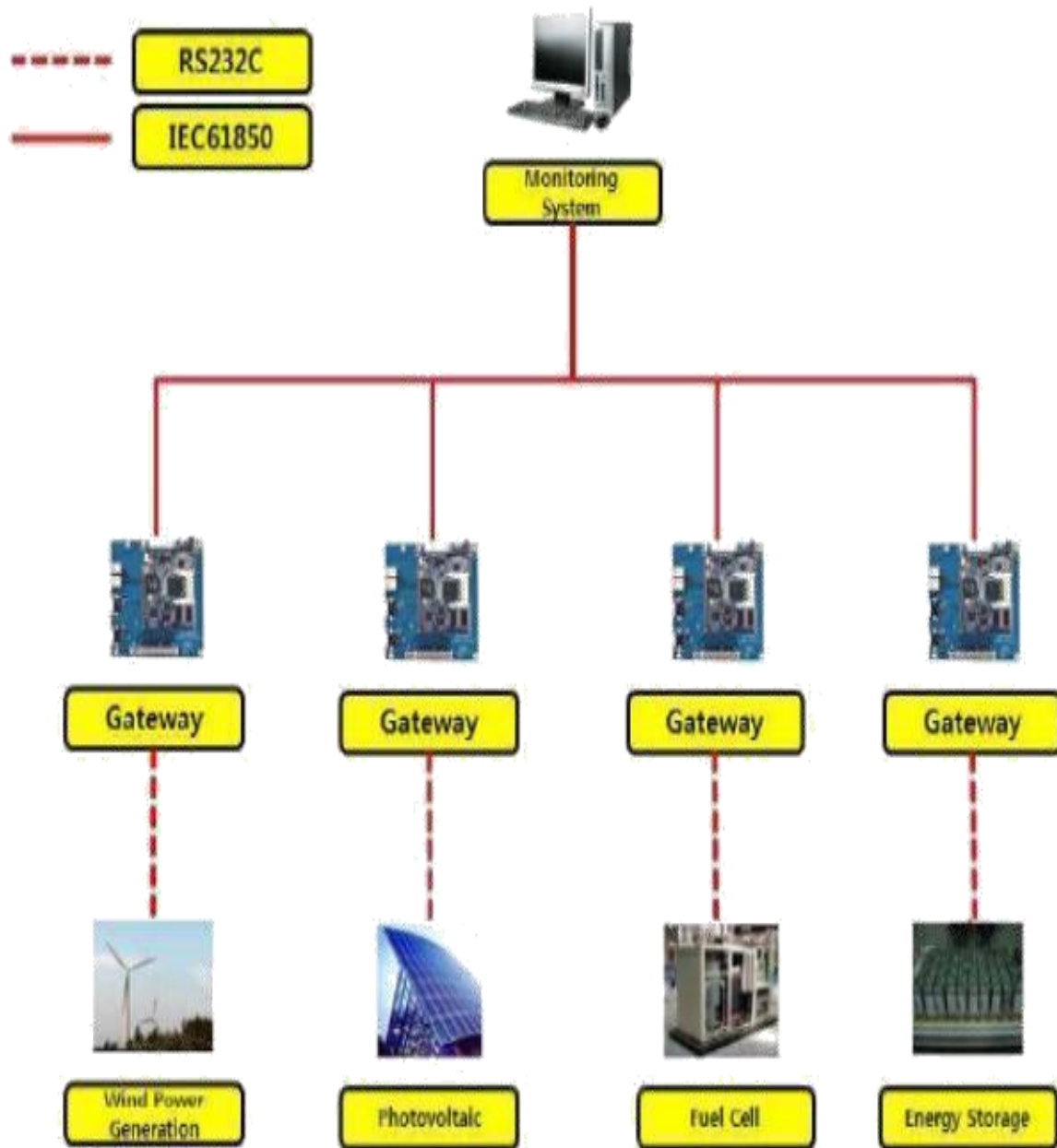


Figure 7: Micro grid communication architecture [34]

3.1.1 Gateway

The gateway plays two roles: as the master node of the Distributed energy resources control unit over the serial link and as an IEC 61850 server for the micro grid monitoring system over the Ethernet link.

Different IEC 61850 servers are implemented for different DER control units. The Gateway has two communication interfaces. The serial Interface and the Ethernet interface. The gateway receives data from a DER controller using the serial link with the proprietary protocol developed in the present work, after which it transfers data to the micro grid monitoring system using the Ethernet with the IEC 61850 protocol. As long as data mapping between the proprietary protocol and the IEC 61850 data model is possible.

The gateway sends report messages to the micro grid monitoring system when data received from a DER controller is different from what the gateway has or within the pre-defined period.

3.2 IEEE 1547

IEEE 1547TM 2003 Standard for Interconnecting Distributed Resources with Electric Power Systems was accepted by the IEEE Standards Board at its June 2003 gathering and was published in July. This standard is the primary interconnection standard auxiliary standards for testing, applications, and communications are under improvement by IEEE work groups. The 1547 standard is the only systems-level technical standard of consistent necessities and specifications universally needed to interconnect DR with the grid.

3.2.1 Need for an Interconnection Standard

Distributed generation (DG) not only provides local benefits to its owner, but it also offers new options for utilities. These options range from a physical hedge alongside purchased power to alternatives to transmission and distribution system upgrades or construction.

Understanding how DG systems are designed, interconnected, and operated is key to understanding the effect of DG on electric power systems and on utilities, goals of maintaining system and supply source reliability. Interconnecting DG to electric power systems can involve system engineering, safety, and reliability considerations [28]. The traditional radial feeders most common on power distribution systems were not designed to accommodate two-way flow of power from active generation and storage at the distribution level, and the technical issues associated with this type of operation are significant.

Developers have found that the differing interconnection requirements of utilities from state to state, and sometimes within a state, have acted as a barrier to the rapid deployment of DG

technologies. Industry and government have concluded that a standard approach to DG interconnection would lower some of the barriers to DG development. Producers and users of distributed power systems have recognized the importance of having a single document of consensus, standard technical requirements for DG interconnection to avoid having to conform to numerous local practices and guidelines [34]. The single standard was needed to provide uniform criteria and requirements relevant to the performance, operation, testing, safety, and maintenance of the interconnection.

The fundamental principles of IEEE 1547 development included:

- A focus on mandatory necessities universally needed for interconnection at the distribution level
- Technology-neutral technical requirements
- Inclusion of DG units with an aggregate size up to 10 MVA at one interconnection point.

Power engineers and other stakeholders looking to the future now have the opportunity to draw upon the published IEEE 1547 and the increasing DG experiences and resources coming to light. But even after publication of IEEE 1547, additional barriers remain to the orderly transition to the integration of all distributed power sources with EPSs.

For example, a lack of straightforward responsiveness is sometimes the case for decisions regarding national building and safety codes and permitting as well as for state public utility commission and local utility judgments. And it is often touted that present power distribution system technology and operation do not inherently allow the full realization of the benefits of distributed power. However, the concerns underlying these issues are often less attributable to technical foundations than to misunderstandings and lack of experience.

The IEEE P1547.2 draft application guide to IEEE 1547, when complete, will provide utilities and DG owners/developers with an approved, hands-on document that outlines alternative methods of addressing the requirements of IEEE 1547. Although IEEE 1547 provides the technical requirements for interconnection on a functional basis, P1547.2 will describe rationale and background for further understanding (e.g., protective relaying and coordination hardware

arrangements, grounding configurations, etc.) to help address the functional requirements of IEEE 1547.

3.3 IEC 61400-25

Wind power plants have through the years steadily gained a bigger and more dominant Position in the power generation industry. Each vendor has their proprietary solutions on controlling and monitoring of the products supplied. In today's ever changing and rapidly growing energy market, monitoring and easy communication is essential. Through this communication the current state of the individual power plant can be controlled and monitored when required, and counter measurements can be enforced if needed in order to supply the demand for energy and keep the stability of the distribution system. It is vital that the overall dispatching systems are able to control the energy generation from a wind farm on demand in order to meet the fluctuations in the energy consumption [35].

A common way to achieve this is a vendor independent approach. IEC 61400-25, Wind Plant Communications, and Expected Output: based on IEC 61850. The IEC 61400-25 series defines communication for monitoring and control of wind power plants. The modeling approach of the IEC 61400-25 series has been selected to provide definitions of classes and services such that the specifications are independent of specific protocol stacks, implementations, and operating systems [35]. IEC 61400-25 defines protocols for communication, control, and monitoring of wind power plants (WPP). This standard includes a wide range of mandatory and optional elements, ranging from security, communications interface, and system speed. This enables control and monitoring to be handle communication in a standardized and secure way. An analysis \focusing on isolating the necessary requirements of IEC61400-25 has been carried out to create a generic prototype which can be used by WPP vendors where main communications interface of the prototype utilizes web services.

The prototype is comprised of several independent modules to allow the possibility of choosing a fully customizable setup by the end user. Configuration of the system need to be done in an easy way, ensuring a flexible and reusable system, where different choices for the system can be added or left out depending on user specifications. From the requirements a prototype with the purpose of examining the key aspects of these definitions has been elaborated The mapping of these classes and services to a specific communication profile is not within the scope of this

part of the IEC 61400-25 series but within the scope of future IEC 61400-25-41 [35]. To reach interoperability, all data in the information model need a strong definition with observe to syntax and semantics. The semantics of the data is mostly provided by names assigned to logical nodes and data they contain, as defined in this part of the IEC 61400-25 series.

Interoperability is easiest if as much as possible of the data are defined as mandatory. It should be noted that data with full semantics is only one of the elements required to achieve interoperability. Since data and services are hosted by devices (IED), a proper device model is needed along with compatible domain specific services (see IEC 61400-25-3).

This part is used to specify the definitions of a logical device class, logical node classes, data classes, and abstract common data classes. These abstract definitions are mapped into concrete object definitions that are to be used for a particular protocol. The compatible logical node name and data name definitions found in this part and the associated semantics are fixed.

IEC 61400-25 series implementations are application specific. The IEC 61400-25 series does not guarantee a certain level of performance. This is beyond the scope of the IEC 61400-25 series. However, there is no underlying limitation in the communications technology to prevent high speed application (millisecond level responses)

4 MODELLING

4.1 INTRODUCTION

The Electrical Power demand is increasing steadily and there is a great need to properly design the future grid for reduced costs and increased reliability. System planning must consist of an integrated approach to both location of resources and their interconnection, rather than a series of unprepared and incremental responses to load growth. In this context, distributed energy resources (DER) have gained increasing attention as an alternative to conventional generation systems. In order to exploit the reliability, security and economic benefits of DER, it is necessary to design DER networks that are potentially self-sufficient. In other words, it is necessary to develop effective tools for microgrid design.

A microgrid should not only network DERs with load points, but should also have the ability to operate in both grid-connected and islanded modes. Microgrid architecture consists of optimally designing the interconnections, as well as optimally sizing and sitting the DER units to maximize reliability, security and product which can be used for space heating too [36]. So a better way to realize the emerging potential of distributed generation is to take a system approach which views generation and associated loads as a subsystem or a “microgrid” [37]. Due to the strong growth of market share of DER, today’s electric power system of centrally located generation, transmission networks and distribution networks is expected to evolve into an infrastructure where small-scale distributed energy resources and loads, connected through local microgrids, are common. The success of such radical transformation will greatly rely on the availability of methods and techniques that enable the economic, robust, and environmentally responsible integration of DER [38]. The interconnection standards may have to be further united and broadened to mitigate any transient stability issues [39].

Analytics and visualization incorporate the remarkable increase in data from the field devices and integration with other applications, and they will demand advanced filter and analysis tools.

Visualization of the data provides a detailed but clear overview of large amount of data. It will help fast analyze network conditions and improve the decision-making process. Visualization in

a higher data management system would help demonstrate precise network performance at each geographically referenced point on a regional or system.

In the stage of planning and design of microgrid, it is required to simulate the proposed system in such a way that it generates large numbers of data from almost every point of the system in the form of voltage, current, power factor, active and reactive power etc. In this paper the authors have proposed some feasible methods for microgrid analysis. This effort also supports feasible operation of microgrid in grid connected mode and islanded mode [40].

A systems perception is necessary for customers, utilities, and society to capture the full benefit of microgrid as an energy system; and the dealing for improved acceptance of these advanced concepts will be driven by lowering the cost and increasing the performance value of microgrids. The improvement of microgrid concept involved with intelligent power electronic interfaces, an intelligent bypass switch for grid disconnection and restoration was created specifically to lower the cost and improved reliability of small scale distributed generation systems with approximate installed capacities in the range of 10kW to 100kW [38]. In this chapter a Simulink based microgrid is considered for the purpose of simplified simulation.

4.2 Microgrid: Integration of Distributed Energy Resources

4.2.1 Concept of Microgrid

The microgrid, an emerging solution to power crisis in near future due to scarcity of fossil fuels, is an integrated form of several types of distributed energy resources with the facility of localized generation thus minimizing the transmission and distribution cost. It should have the capacity to work under grid connected mode and standalone mode. A proposed path to recognize this promising potential of distributed generation is to take a system approach which views generation and associated loads as a subsystem or a “microgrid”. The sources can operate in parallel to the grid or can operate in island, providing uninterrupted power supply. The system will disconnect from the utility during large events (i.e. faults, voltage collapses in the grid), but may also intentionally disconnect using intelligent bypass switch when the quality of power from the grid falls below certain standards [37].

Microgrid is formed by the interconnection of DERs [42] such as microturbine, photovoltaic cells, wind turbine, fuel cells etc. together with storage devices (batteries, energy capacitors, fly

wheels etc.) and controllable load (with critical & non-critical selectivity control) at low voltage distribution system [41]. A schematic representation of a typical microgrid study system and its simulated model are represented in Figure 8 & 9 respectively.

4.3 Microgrid Simulation

4.3.1 Objectives of Simulation

To analyze performance of microgrid on planning stage, it should be studied thoroughly. In the present work, a typical sample microgrid is formed with suitable assumptions using Simulink showing feasibility of grid connected and standalone mode of operation including critical and non-critical load discrimination during grid failure. The main objective of this section is to study the feasibility of the proposed model by steady state analysis under grid connected mode and islanded mode. The model is also studied for the transient condition when the microgrid transfers from grid connected mode to islanded mode. Furthermore, the system is studied as linear time invariant system (LTI) analysis for step response of the line currents against step change in the grid voltage for study of dynamic stability analysis of the proposed model.

4.3.2 Assumptions for microgrid modeling

There are different types of DERs available, some of which output dc voltage and the same is to be converted to ac voltage using power electronic based inverter, e.g. PV generator, fuel cells etc. Again, the DERs like wind –turbine generating set, CHP system using microturbine etc. finally output ac voltage. This type of source, when connected with ac utility grid or working under standalone mode driving ac load, eventually, acts as an ac source for the concerned application. In the present work, all DERs are assumed as ac source forming microgrid for simplified presentation of simulation of microgrid integration and operation in grid connected mode and stand alone mode.

The line voltage of microgrid is considered as 11 kV and the typical grid discussed here is treated as per phase basis with 60 Hz system frequency. The details of loads are shown in Table 4.1.

Table 2: Laods Connected with Microgrid

<i>Type</i>	<i>Nature of Load</i>	<i>Active Power [kW]</i>	<i>Reactive Power[kVAr]</i>
Critical Load1	Inductive	100	50
Critical Load2	Inductive	200	100
Critical Load3	Inductive	300	150
Non-critical Load2	Inductive	200	100
Non-critical Load2	Inductive	100	50

Microgrid with three DERs connected with Grid supplying smaller loads are simulated with three numbers of DERs (DER1, DER2 & DER3) and the network is connected with grid, critical loads and non-critical loads. Since microgrid can facilitate localized operation minimizing major conductor & transmission line erection and commissioning cost; short line lengths are considered from one DER to another as 1 km.

For analysis purpose, equal fixed length of each line is assumed and for such short distance the line capacitances are ignored. With high voltage long transmission lines, the resistance R may be neglected and reactance X is many times greater than that of resistance ($X \gg R$). But microgrid can be based just on mainly resistive LV distribution network where resistance is more than that of inductive reactance ($R \gg X$). This work deals with the same assumptions for line parameters of microgrid.

4.3.3 Description of Microgrid System

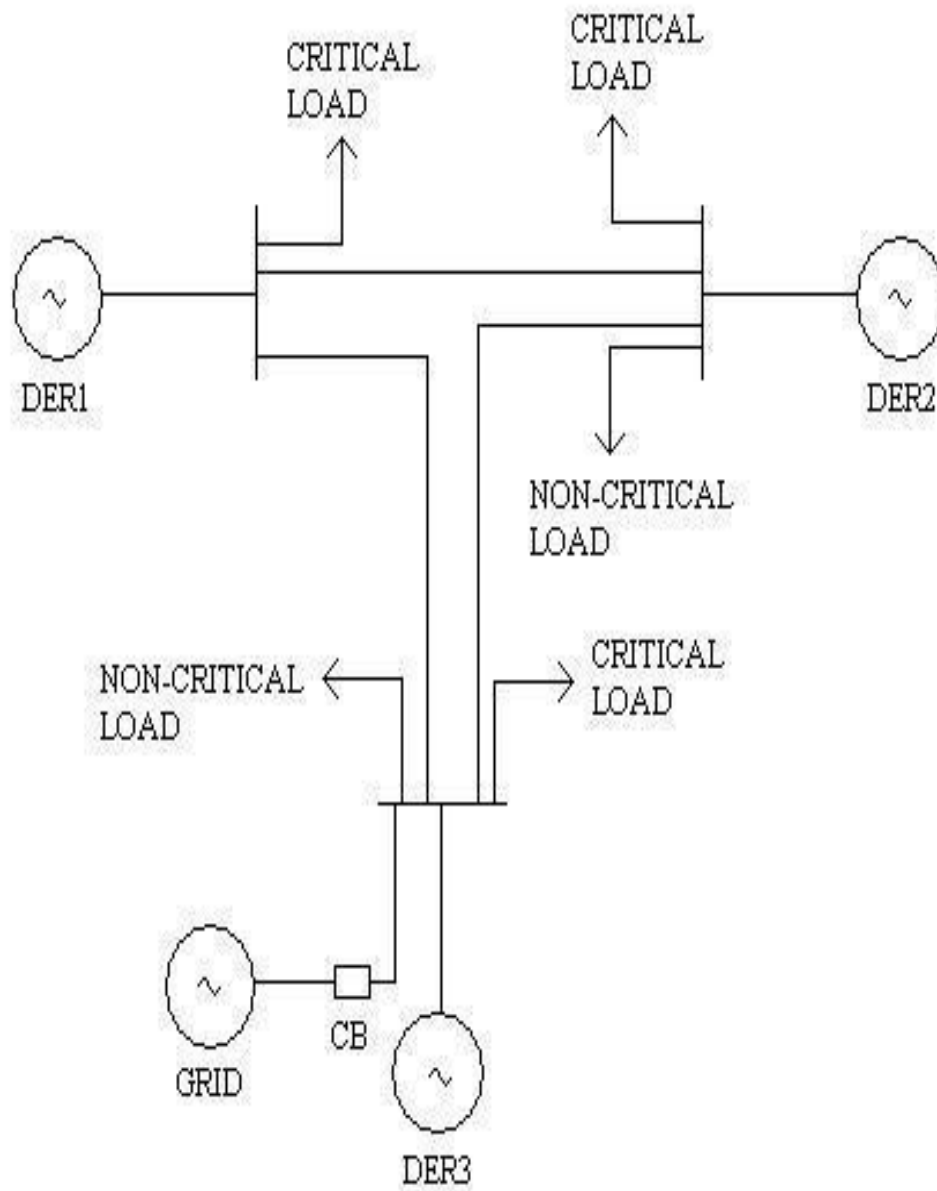


Figure 8: Typical Microgrid [35]

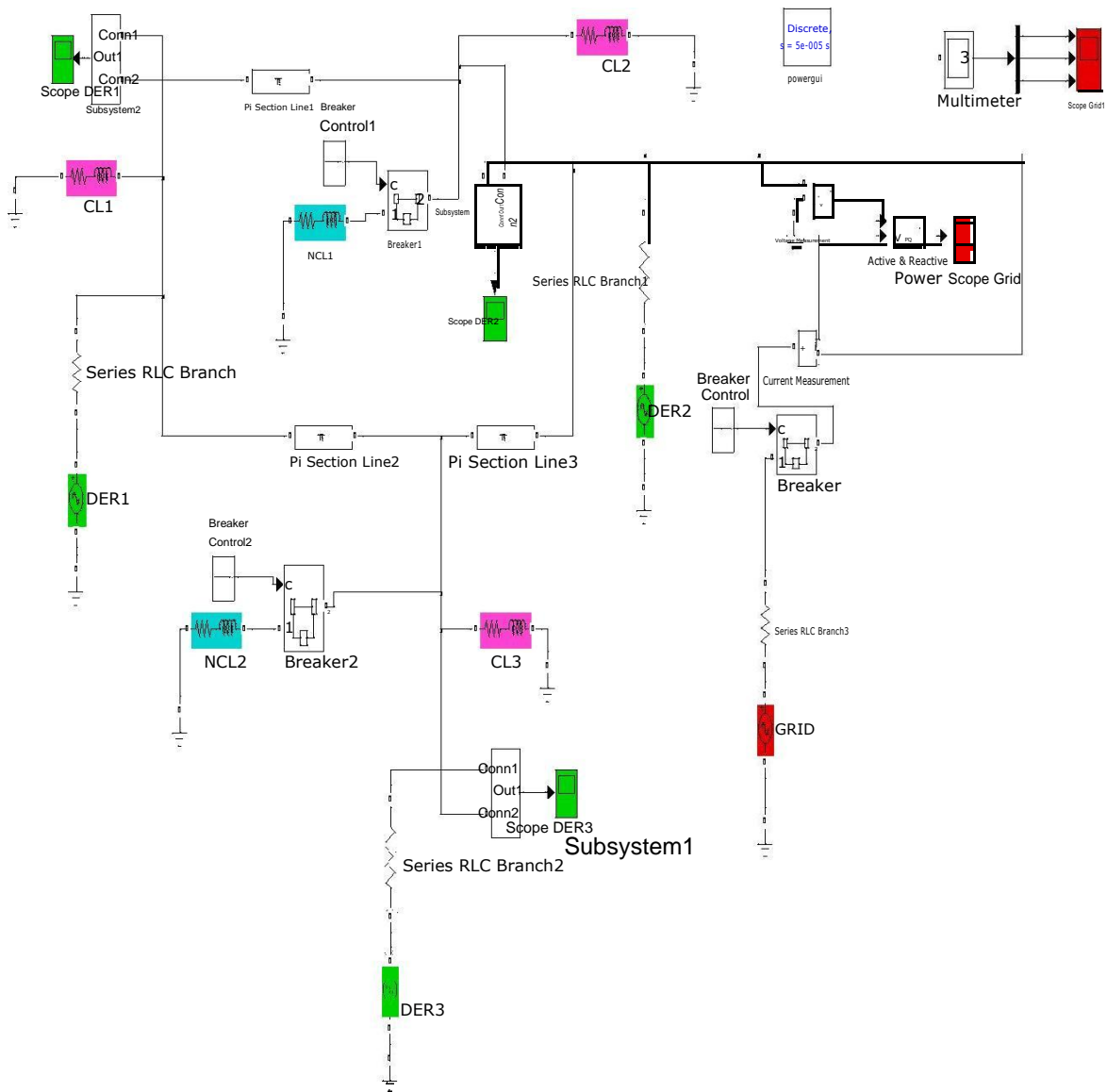


Figure 9: Simulink Model of Microgrid

A single line diagram of the microgrid system studied in this section is illustrated in Figure 8, 9. In this model, three numbers of microsources are considered as ac source along with utility grid. The single phase system voltage is 230 V. This proposed model has provision for working as grid connected & stand alone mode with critical and non-critical load selectivity. The waveforms of currents and voltages at different points are obtained using multimeter block in Simulink. The critical and non-critical load selectivity is provided by circuit breaker blocks by time based

activation simulating the basic requirement of the communication architecture among all the components. In the grid connected mode, microgrid operates connected with grid and supplying power to critical and non-critical loads.

4.3.4 Transient State Simulation of Microgrid

In transient state simulation, for the first 3 second, the microgrid remains connected with utility grid and after 6 Second of disconnection, the utility grid is restored at ninth second. The wave form of the grid is shown in red colour in Figure 10. During the period of grid outage, priority is given to supplying critical loads instead of non-critical loads. So the three numbers of critical loads remain connected with microgrid during islanded period.

In Figure 10, the critical load1 (CL1) current is shown with blue colour. Out of two numbers of non-critical loads, Non-Critical Load1 is disconnected from microgrid after 4 second (shown in pink colour) and the other one (NCL2) is disconnected after 5 second of operation (shown in black colour). After 6 seconds of islanded operation, grid is restored at 9th second of simulation and both non-critical loads are re-connected with microgrid at 9.5 second.

In this work, implementation of critical and non-critical load selectivity along with additional discriminating approach for even several non-critical loads are proposed for implementation of communication devices. For this purpose, a control unit is to be provided with priority setting for different types of loads and the same should send instructions through wireless mode to the circuit breakers for necessary closing or opening operation.

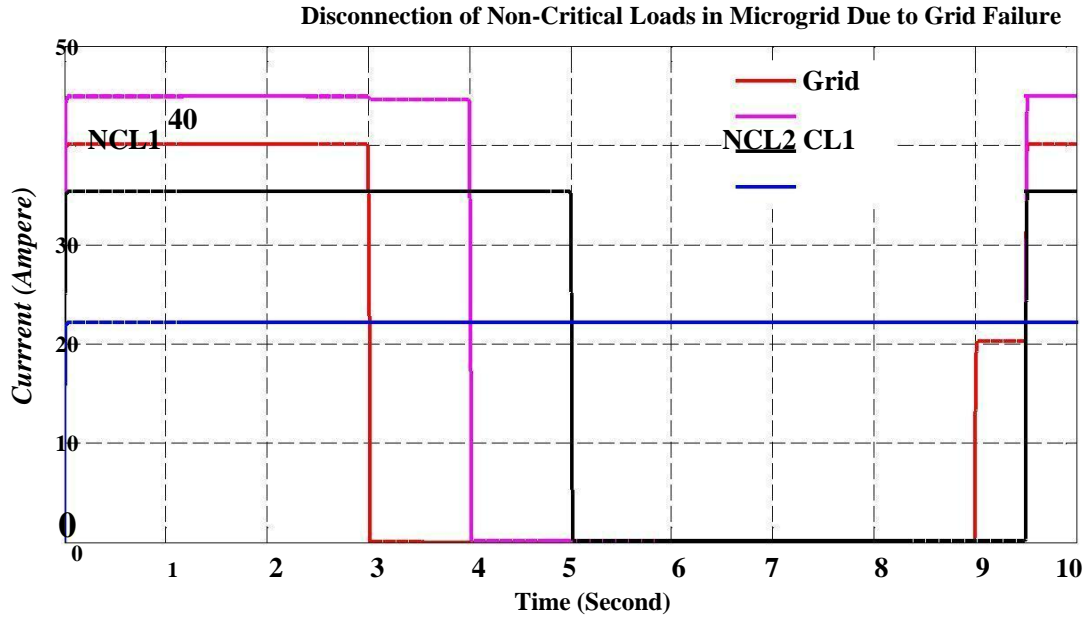


Figure 10: Wave forms of Currents in Transition State of Microgrid

This chapter presents microgrid analysis at the stage of designing and planning for proper utilization of distributed energy resources. The analysis is based on observation of electrical parameters through steady and transient state studies in the perspective of integration of DGs. Simulation of microgrid is performed using Simulink in Matlab software. This type of analytical approach can be applied to study more complex system too.

5 Conclusion

In this work it is realized that implementation of communication technology is an essential criteria for satisfactory and fast automated operation of microgrid system. The latest communication protocols such as IEEE 61850, IEC 1547 etc are identified which are suitable for microgrid application the basic mode such as grid connected and Islanded modes are studied through modeling and simulation in which elementary and simplified aspect of communication technique is tested and found satisfactory.

5.1 Future scope

The present works have several aspects for further research an implementation of communication system in microgrid. Further study may be carried out for sensing fault current, surge voltage, Grid outage etc, through installation of proper communication devices in microgrid architecture.

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