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State of art: Micro-grid and intentional islanding of hydro distributed generation

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ABSTRACT

A conventional power system is a centralized architecture in which power is generated is relatively large power plants, transmitted at high voltages and delivered to many loads that can be hundreds and even thousands of miles away. The technical solution is to integrate small and Distributed Generations (DG) sources into the grid at various voltage levels. The current engineering practice for DG/Utility interconnected systems is to revert the utility systems to its original configuration (radial or meshed distribution systems) with all interconnected DG units de-energized whenever an unexpected disturbance occurs in the system. Thus, the system reliability stays at the same level as it was before integrating the DG. If connected DGs are permitted to work as microgrid and supply the local load during utility outages, the system reliability will be much better and the customers will not experience any discontinuity of their supply and can avoid loss of generation within the microgrid. When DGs operate in a microgrid environment, a central control and coordination are required. Microgrid Central controller (MGCC), a supervisory controller which co-ordinates operation between the DG, the utility grid and the algorithm is considered for the above case. The study results show that during the islanding operation the frequency and voltage are within the acceptable limit. By implementing proper control and protection schemes, DGs can be used as alternative generation backup within the microgrid during the loss of supply and hence system reliability can be improved and loss of generation can be avoided. Electric utilities should, therefore, pay special attention to their existing control and protection systems in order to incorporate intentional islanding operation in their system to retain integrity.

Keywords— *Microgrid, Intentional islanding*

1. INTRODUCTION

Electrification is considered the greatest engineering achievement of the twentieth century. In most typical power systems, power is generated at a member of large centralized power stations. The transmission and distribution (T&D) system are used to transport this centrally generated power to the consumer. The basic design of power system based on centralized architecture, in which relatively few large power plant delivering many loads that can be hundreds or even thousands of miles away is essentially unchanged, even with the recent initiatives with 'smart grid' and integration of DG. The requirement of continuity leads to very high standards of reliability. Electric power grids are showing signs of deterioration due to aging and usage that stresses these systems beyond designed safety margins. The existing technology is inadequate to meet the evolving and growing needs of society. The existing infrastructures are facing serious aging problems, for example, more than 50% of the substation transformer is more than 35 years of age. The task of running the power system remains as complex as ever and is constantly facing new challenges. The technical solution to these problems is the integration of distributed generation sources into the grid. This is basically, the same concept that Edison proposed in the late 1800s as a counterpoint to Tesla's concept that prevailed into present power grids because at the time technology was not sufficiently developed to implement Edison's concepts. Today the technologies exist and Edison's concept can be practically implemented thereby increasing operational flexibility, efficiency, and reliability while lowering capital cost. Advanced development in the technologies related to power electronics, energy storage intelligent controls and communication systems have made it possible. Integration of distributed generations powering relatively small power systems called microgrids may be the only option to truly addressing the problems affecting power grid.

2. CONVENTIONAL GRID

The design of the current power system grid is a centralized architecture illustrated in figure 1below, in which power is generated in relatively few large power plants, stepped up to the high voltage and transmitted over large distances, stepped down to distribution voltage and delivered voltage and delivered to the local loads using radial or meshed distributed network.

This centralized architecture had its origin from Nicola Tesla's discovery of alternating current(AC) for transmitting power and William Stanley'sinvention of the first practical AC transformer in 1886. Alternating current became the preferred method of power transmission due in large part of the transformer. This is because transformers can reduce the amount of current sent over power lines by "stepping up" voltages with very few losses in the process. This allowed for much greater distances between the generally large, noisy and polluting power plants of the time and utility customers. Thus, the modern power grid model of a few large power plants sending power long distances at high voltages to lower voltage distribution systems was created, while independent power production was only utilized when the grid could not be accessed.

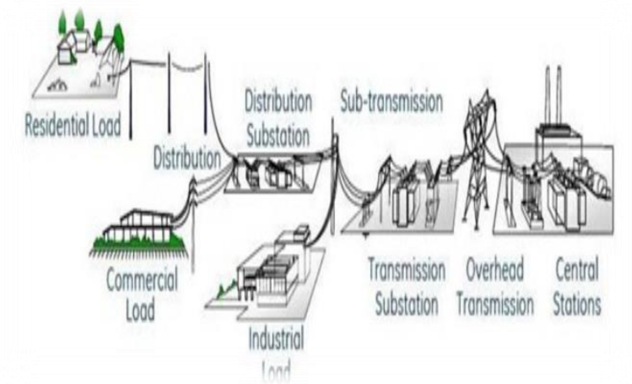

Fig. 1: An electric power system

3. GRID MODERNIZATION

At present, Grid is not dumb and there is continuous modernization in the grid. Power electronics interfaces and internet revolutionized communication systems are the main enabling technology for modern power grids. Stationary power electronics systems started to develop more attention to the development of computers because of their challenging power conversion needs. A dumb system becomes smart by sensing, communicating, applying intelligence, exercising control and through feedback, continually adjusting. Modernization of grid is due to developments in technologies like smart grid and smart sub-stations, integration of distributed generation, small power injection at various voltage levels, SCADA, Distribution Automation & Advanced Controls and protection.

4. INTEGRATION OF DGs AND SMALL POWER INJECTION AT VARIOUS VOLTAGE LEVELS

With the increasing demand for power, the need for commissioning new generating units is increasingly becoming a necessity. Apart from the heavy investment and the complexities involved in setting up large generating stations, setting up of new generating units call for upgrades to the transmission network to transport the power generated to the load centers. Updates to the transmission network are economically constraining, and therefore, distributed resources are being considered to avoid these problems. Over the last decade, distribution systems have gradually seen a large number of DGs because of they are becoming more efficient and less costly and have been promoted by incentive financial policies by means of an adder or feed-in tariff mechanism. Since its creation in 1881, the operation of the electrical power system has not drastically changed until recently. Through the integration of new technologies, such as DG, the classical unidirectional power flow has slowly changed to bi-directional power flow, allowing the active participation of the consumers and users on the electrical network. DG refers to small sources of electric power generation or storage that is not a part of a large central power system and is located close to the load. DGs can be powered by renewable energy and conventional resources such as photovoltaic (PV) solar arrays, wind turbine, fuel cells and biomass fuel, as well as gas-fired combined heat and power plants yielding high efficiency, standby/emergency generation resulting in enhanced efficiency, peak shaving, grid investment deferment, and premium power. At the same time islanding, voltage regulation, harmonics, modified power flows, protection, and metering are some major issues concerning DGs. A better way to realize the emerging potential of distributed generation is to take a system approach which views generation and associated loads a subsystem or a "Micro-grid".

5. IMPACTS OF DISTRIBUTED GENERATION

Due to the benefits, it brings DG has been rapidly growing in number in the last years, becoming an important component of the worlds future power systems. DG has the advantage that it may be connected closer to the end user thus reducing transmission losses. Some of the benefits of changing to a decentralized power system include:

- Avoiding the need for building new infrastructure in the network.
- Reduce the distribution network power losses.
- Increase the flexibility of the system.
- Provide service support improving the continuity and reliability.
- The integration of DG has multiple influences over the grid operator. The following are the technical issues are described as
- Power quality
  - -Harmonics
  - -Frequency and
  - -Voltage fluctuation.
- Power fluctuation.
  - -Small time power fluctuations
  - -Long time or seasonal power fluctuations
- Storage
- Protection issues
- Optimal placement of DG
- Islanding.

6. ISLANDING

Islanding is a condition in which a micro-grid or a portion of the power grid, which contains both load and DG, is isolated from the remainder of the utility system and continues to operate. The disconnection of the DG once it is islanded is required by the interconnection standards.

Issues with Islanding:

- Lineworker safety can be threatened by DG sources feeding a system.
- The voltage and frequency may not be maintained within a standard permissible level.
- Instantaneous reclosing could result in out of phase reclosing of DG.

6.1 Overview of Distributed generation, Islanding of DG and Micro-Grid concept

With the increasing demand for power, the need for commissioning new generating units is increasingly becoming a necessity. Apart from the heavy investment and the complexities involved in setting up large generating stations, setting up of new generating units call for upgrades to the transmission network to transport the power generated to the load centers. Updates to the transmission network are economically constraining, and therefore, distributed resources are being considered to avoid these problems. Distributed generation is defined as demand- and supply-side resources that can be deployed throughout the electric distribution system to meet the energy and reliability needs of the customers served by that system. DG refers to small sources of electric power generation or storage (typically ranging from less than a kW to tens of MW) that is not a part of a large central power system and is located close to the load. DG has several advantages when connected to the electric power system including combined heat and power plants yielding high efficiency, standby/emergency generation resulting in enhanced efficiency, peak shaving, grid investment deferment, and premium power. At the same time islanding, voltage regulation, harmonics, modified power flows, protection, and metering are some of the major issues concerning.

Distributed generation technology is now being rediscovered due to several recent trends. The most widely cited are:

- Advancements in the technologies associated with DG
- Concerns of environmental pollution and emission of greenhouse gases resulting from the burning of fossil fuels along with an interest in more environmentally friendly technologies
- An increase in the cost of fossil fuels
- A greater demand for power quality, especially from industry
- The laws, codes, and popular sentiment against building new transmission lines along with the desire of utility companies to reduce costs by building transmission lines

The technology and concept are also being revisited because of the benefits it can provide. The use of DG can improve power quality for utilities in several ways, although each depends on the location and type of DG used. The use of DG can strengthen the system voltage profile and can reduce both real and reactive power system losses when located near loads at the end of lines. The units that can operate in standalone mode can provide power quality benefits to customers by supplying sections of the power system grid when there are outages on other sections of the distribution system. Some have even speculated that both permanent and temporary outages could be virtually eliminated if the technology were developed further and used independently of the power grid.

7. INTENTIONAL ISLANDING AND RELIABILITY OF POWER SYSTEM

Distributed generation has the ability to reduce both temporary and permanent outages on distribution systems, but this generally requires what is called intentional islanding, although it is possible to switch a section with distributed generation onto a separate feeder without creating an island. Islanding usually occurs when a section of the distribution system supported by DG is disconnected from the main substation during a transient. Islands are not inherently harmful to distribution systems, although most utilities utilize some form of anti-islanding protection due to problems associated with islanding. One of the major problems with islanding is that it is often caused by faults that occur between the DG and the substation, which often results in relays opening at different times to remove fault current and results in a loss of phase and voltage synchronization. The loss of synchronization can result in large transients when a re-closer operates to reconnect the island and can then result in false tripping. A further problem with islanding is that, even if synchronization is not lost during the relay operation, synchronism can be lost after the island is created because the generator may not be capable of supporting the island and this may result in damage to the generator as it speeds up to attempt to meet the load demand. The Standards Coordinating Committee of the IEEE devised a set of recommendations for utilities to follow for interconnection between distribution systems and DG and these became the IEEE 1547-2003 Standard. The standard recommends anti-islanding protection operate within two seconds of detecting an islanding condition[18], while also putting forth recommendations for disconnecting during under/over-voltages and under/over frequency events, although these types of events are often an indication that islanding has already occurred. Studies have been conducted examining both improvements in reliability from DG and methods for preventing islanding, with mixed results. One study of a simple distribution system with DG on a lateral found that the hours of power unavailability for customers could be reduced by 100 for each additional section of the feeder that could be supported by DG, although the study found that the number of interruptions per year increased slightly. Another study of automatic sectionalizing switching devices used in intentional islanding schemes could reduce system interruptions by up to 90% and the duration of interruptions by up to 82% for one test system. An additional study found distributed generators had a very little effect on the number of outages per year but could have a significant effect on the duration. Intentional islanding operation may be desired in cases where the central grid is prone to reliability problems. In this case, the interconnection is designed to permit the mini-grid to continue operating autonomously and provide uninterrupted service to local customers during outages on the main grid. Usually, protective devices must be reconfigured automatically when transitioning between islanded and grid-connected modes. In addition, islanding systems must include provisions to shed load that exceeds the local generation capacity when operating in islanded mode. Policy regarding interconnection of previously autonomous mini-grids should allow for maintaining the future capability to operate autonomously, provided this can be done safely.

The use of anti-islanding devices has only recently started. Most types, including ROCOF relays, which detect islanding conditions through sudden changes in frequency, and vector surge relays, which detect islanding conditions through phase differences in a generator's internal voltage and the terminal voltage, are found to be difficult to coordinate with existing protection measures or trip incorrectly. To enhance the overall system reliability through intention islanding, a proper interfacing operational strategy between the different protection switchgear components must be identified. Power flow to sensitive loads can be sustained once the principal protection elements are identified under different fault scenarios. Through the adaptation of microprocessor PLC modular units interfacing agents, DG operator can maximize their energy delivery without jeopardizing Utility safety requirements. Meanwhile, Utility can increase the distribution reliability without violating Utility consumer relationship.

8. MICROGRID

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 "micro-grid". Micro-Grids with the increased prevalence of conventional and renewable resources in the power system, it was necessary to cope with these changes in order to operate in an efficient and intelligent way. In other words, it is important to design new approaches that would allow the supply of excessive future electricity demand with less cost expenditure. A new concept that has emerged recently, which is the microgrid approach, that focuses on creating a design and plan for local energy delivery meeting the exact needs of the community constituents being served such cities, hospitals, universities. Micro-grids are composed of a group of DGs connected to the distribution system with both grid connected and islanded capability.

8.1 Definition

IEEE Std. 1547.4-2011 defines DG island systems or micro-grids as electric power systems (EPS) that have DG and load, have the ability to disconnect from and parallel with the area

EPS, include the local EPS and may include portions of the area EPS and are intentionally planned. Micro-grids are power systems that can operate autonomously using combinations of conventional generation technologies such as diesel gensets and combined heat and power systems, renewable resources, other new generation technologies, such as micro-turbines and fuel cells, energy storage systems, and load management systems. In many ways, a micro-grid is really just a small-scale version of the traditional power grid that the vast majority of electricity consumers in the developed world rely on for power service today.

The most immediate sites for application of the Micro-grid concept would be existing remote systems which consist of a bundle of micro-sources and loads, for example, Figure 2. It could be prohibitively expensive to compensate for load growth or poor power quality, by upgrading the long supply line and the feeder to the (weak) source bus. Upgrading the local sub-system to a Micro-grid could be a cheaper option. A necessary feature of such a Micro-grid is that it can act as a semiautonomous system, i.e. when the main network is not available, the Micro-grid can still operate independently. This also has the potential to significantly improve the power quality of Micro-grid systems by allowing them to ride through some faults. This is an advantage for sub-systems in larger installations requiring heterogeneous power quality.

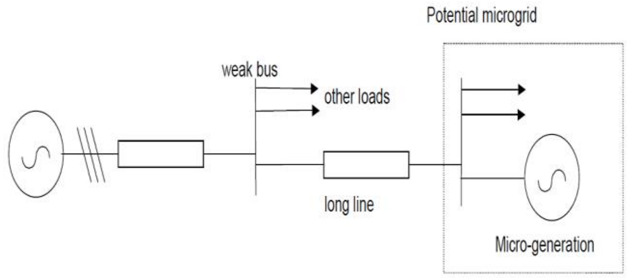

Fig. 2: Micro-Grid application

This combination of units is connected to the distribution network through a single Point of Common Coupling (PCC) and appears to the power network as a single unit. The system must be capable of operating despite changes in the output of individual generators and loads. It should have plug-and-play functionality: it should be possible to connect extra loads. Likewise, it must be possible to add generation capacity with minimal additional complexity. Key, immediate issues for the Microgrid are power flow balancing, voltage control, and behavior during disconnection from the point of common coupling (islanding).

The four core functions of a micro-grid:
(i) To regulate the voltage amplitude and frequency in a micro-grid within a normal rate when functioning in the islanded mode.
(ii) To allocate each power from an energy resource, whether active or reactive power, to load when operating in the islanded mode.
(iii) To enable power exchange between a micro-.grid and the utility in the grid-connected mode.
(iv) To ensure easy transfer between the islanded mode and the grid-connected mode.

One of the major challenges is to design protection as well as control techniques for micro-grid to enhance stability and smooth transition between two modes, namely, the grid-connected mode and the islanded mode. This requires several key aspects that include control, synchronization, and islanding detection, as shown in the figure.

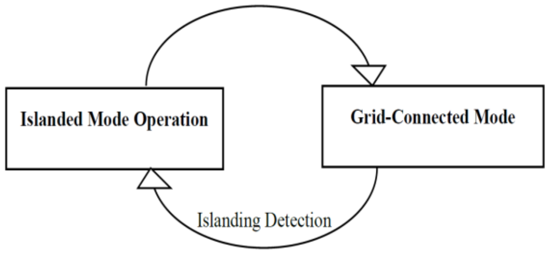

Fig. 3: Synchronization restoration

8.2 Necessity of micro-grid

Traditional centralized generating systems can sometimes be unable to meet the potential growth of future electricity demand at an acceptable cost. Thus, micro-grids are expected to cope with these changes positively on a technical, economic and environmental level. Technically speaking, micro-grids establish a reliable plan that integrates redundant distribution, smart switches, automation, and independent power generation and storage in order to solve emerging issues and eliminate black-outs. Smart switches and sensors fix and anticipate power disturbances, unlike traditional ones. Equally important, micro-grids can provide voltage support, improve power quality as well as increase system reliability by supplying power during utility outages.

- From the economic perspective, DGs can supply the customers by constructing new distribution lines that can meet their needs especially for remote places that cannot easily be supplied by the utility. Three main stakeholders; the DG owner, utility, and the customer can benefit economically from installing DGs. The DG owner can get additional revenue and reduce.
- From a futuristic point-of-view, this technology is strongly needed to be a part of today’s vision by finding eco-friendly solutions with the use of micro-grids. It is a proven method for the future as it can meet known and unknown future needs by allowing communities to increase overall electricity supply quickly and efficiently through renewable energies such as small local generators, solar cells, and wind turbines. In addition, smart grids enable plug-in-electric vehicles. The ability to use local renewable or natural gas energy generation will make this a more versatile system. Smart grids can reuse the energy produced during electricity generation for heating building, hot water, and sterilization.
- The effectiveness of micro-grids is further enhanced through energy storage. Storage systems not only provide backup power while the microgrid's generation sources are coming online, but they can also be used to regulate the quality of the power and protect sensitive systems like hospital equipment that may be vulnerable to power surges during restoration efforts.
- Micro-grids offer additional advantages. Surplus power from micro-grids can be sold to the central grid or stored for later use. In combination with energy storage and energy management systems, micro-grids can also provide ancillary services to the broader electric grid such as voltage and frequency regulation. Micro-grids also reduce dependence on long-distance transmission lines, reducing transmission energy losses.

8.3 Implementing intentional islanding operation of micro-grid

Micro-grid Central Controller: Micro-grids is a bundle of distributed energy resources and loads, comprise different units located at a distance from each other. There is a need for maintaining coordinated operation and control within the micro-grid to maintain stability in the system and accomplish the goals of the microgrid.

The Micro-Grid Central Controller (MGCC) is the supervisory controller which coordinate automated power system operations, a peer-to-peer high-speed communications-assisted protection scheme, operation of the local generator controllers and a fast load-shedding system through a communication network. There are multiple agencies within a state engaged in the generation, transmission, and distribution of electricity. State Load Dispatch Centre monitors these operations and keeps the account of the quantity of electricity transmitted through the state grid. SCADA is a part of it. SCADA is the technology that enables a user to collect data from one or more distant operator to stay or visit frequently to the work locations. It includes the man-machine interface. It allows an operator to make setpoint changes on distant process controllers, to open or close valve or switches, to monitor alarms to collect measurement information is best applicable to processes that are spread over large areas. SCADA is a high tech computer system with an associated communication network that enables supervision and control of power system network implemented all over the state at each substation and generating stations for online monitoring, measurement, and control of complex transmission system network. The SCADA control centers acquire data from its own area and execute the command through tele-control via IEC 61850 protocol. By using this system real-time information is gathered through the SCADA System, MGCC receives real-time information of power system, the status of circuit breakers, information from the generator controller and monitoring systems in the micro-grid and takes decisions from a system point of view. Based on logic developed for the micro-grid scheme, coordinated operation, and control within the micro-grid, communications-assisted protection scheme, a fast load-shedding system for automatic load disconnection & restoration is achieved through the control output of Remote Terminal Unit (RTU) installed at the substation and generating station for SCADA System. The MGCC can be very beneficial for managing the overall stability of the micro-grid. Decisions such as when to island the micro-grid can be crucial for the operation of the micro-grid. It monitors the point of common coupling (PCC), analyzes the power quality at the PCC and decision of islanding operation of micro-grid is taken. It also monitors power generated by the generating unit and power flow within Micro-grid. MGCC helps to keep a record of the power flows and system conditions from the past and use those records to forecast the load and plan the generation within the microgrid ahead of time, especially when real-time pricing of power is in place. Since the MGCC is in constant communication with the entire micro-grid, it can also be used as a backup protection scheme of the micro-grid. After islanding, once the grid support is restored, and it is decided to reconnect, the voltage and frequency at the PCC will have to be matched with that on the grid side. The MGCC communicates with the generator controller to regulate voltage and frequency to facilitate re-synchronization with the grid.

8.4 Grid-connected operation mode

Before connecting to the grid, the voltage output from a synchronous generator must be synchronized with the grid voltage. The generator frequency and the grid frequency must be the same, and the two waveforms must be in phase (the peaks must exactly line up); if the waveform is not synchronized, large currents will flow and the generator will be severely damaged. Synchronization can be manual or automatic. Manual synchronization is rarely used with large generators (> 100 kW) and requires a skilled operator, but can at times be used as a backup to an automatic synchronization system.

8.5 Implementing Intentional Islanding

Implementing intentional islanding requires that the system perform several steps, reliably, in correct sequence and timing. The figure shows a block diagram of the control scheme for implementation of intentional islanding operation of Micro-grid. It explains the coordination between different blocks within the Micro-grid. Data is read from all the units by RTU units installed in sub-station and generating station, and it is transferred to the central controller in the LDC and the commanding signal are sent back to each block. The sequence of operation of Micro-grid for grid-connected and intentional islanding:

1. Before connecting to the grid, the voltage output from a synchronous generator must be synchronized with the grid voltage. The generator frequency and the grid frequency must be the same, and the two waveforms must be in phase. DG is synchronized to the Grid by the Auto synchronizer unit. When operating parameters are within the preset limits, the synchronizer issues a close command to the Circuit breaker S2.

2. MGCC continuously monitors the power-flow within the Micro-grid and voltage and frequency at the poInt of Common Coupling (PCC). The island detection unit must recognize an abnormal condition on the utility grid, or loss of main grid and disconnect a circuit breakerS1 located at sub-station to separate islanded micro-grid load from the main grid.

3. Once islanding is detected, generator controller changes from Constant Power Mode to Voltage Control Mode. Meantime turning on a means to keep the turbine spinning at the correct speed. The generator’s Automatic Voltage Regulator (AVR) operated in a Power Factor Control (PFC) mode when connected to the main grid need to switch over immediately to operate in voltage control mode.

4. When the system is islanded, DG will solely dispatch power to the load in the island with the local generating resource. A sudden change in generation overload results in the deviation of frequency during islanding. Frequency stability is achieved by the turbine governing unit with negative feedback, which inlet opens the water input to the turbine as per the load in the islanded system.

5. A large power imbalance with an excessive load may occur leading to under frequency. The generation capacity of DG may no longer be sufficient to supply all of the load in islanded mode. The drop in frequency can occur rapidly and the situation can lead to the system collapse. In the case, the frequency is restored by shedding a certain amount of load so that the system is back into equilibrium. This is achieved by the Load Shedding Control Module (LSCM), which controls the outgoing 11 kV feeder breakers in the 33/11kV sub-station.

6. The system must continue to sense line voltage on the main grid, and when main grid power returns to stable conditions, initiate re-connection, and return to control regimes appropriate for grid-connection. When grid supply restores, the transition from islanded to grid-connected mode takes place. Before re-connection, the micro-grid must be synchronized with the main grid. Once the DG voltage and frequency is synchronized with the main grid a closing command is passed to the Circuit breaker S1 and MGCC continuously monitor for islanding as specified in step 2.

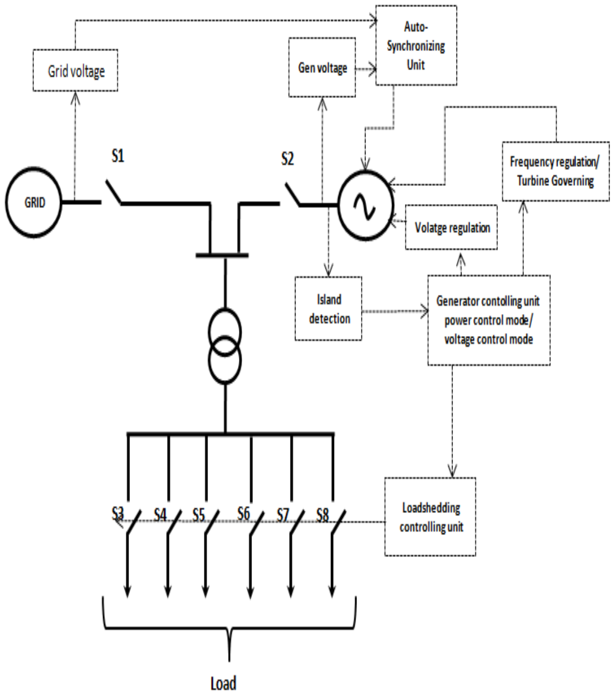

Fig. 3: Block diagram

The MGCC is a supervisory controller which coordinates automated power system operations and generator controller within the micro-grid. MGCC is used to make islanding decisions and during re-synchronization with the grid. It receives status data from the DG, the circuit breakers, and other measurement units in the micro-grid. The status data are studied and commands are generated for the generator controller and transmitted back to them. Data acquisition and transmitting control output is achieved through the constant communication between Central Receiver at LDC and Remote
Terminal Units (RTU) installed at the substation and generating station.

9. CONCLUSION

- Micro-grid is a very good solution for feeding sensitive loads and represents uninterruptible power supply for those loads.
- The micro-grid can switch from grid-connected mode to islanding mode without sacrificing the system stability and no power interruption.
- Loss Generation during grid outage can be avoided.
- Hence, if there is an unplanned outage in the Grid Supply, the customers connected to substation will not be interrupted, thus enhancing the continuity of supply and reliability of the system in this area.
- Overall control and operation of islanding and re-synchronization process are automatically done by SCADA without unloading or shut down the unit. From various study cases, it has been proved that micro-grid islanding operation can apply to other DG connected distribution system in order to enhance the reliability and the continuity of power supply in the current system.

10. FUTURE SCOPE

In the future, the working of the present SCADA system should be studied in detail such that the implementation of the control algorithm designed for micro-grid operation can be successfully implemented on the present power system. This interfacing does not require any further infrastructure development and can be implemented by proper utilization of existing infrastructure without compromising with the grid standards and safety regulations.

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