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Technical Challenges on Microgrids

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***Abstract*—Micro grids are becoming increasingly attractive to consumers and as such in the future, a great number of them will be installed at consumer's sites. In this situation, conventional distribution networks that accept distributed generation connections may face serious difficulty when its control and protection functions become more complicated. This incurs a burden to the network operation and some technical limitations will appear when a great number of distributed generations are installed. One way of overcoming such problems, a micro grid system is formed to provide reliable electricity and heat delivering services by connecting distributed generations and loads together within a small area. A Micro grid is usually connected to an electrical distribution network in an autonomous way and employs various distributed generation technologies such as micro-turbine, fuel cell, photovoltaic system together with energy storage devices such as battery, condenser and flywheel. Micro grids can cause several technical problems in its operation and control when operated as autonomous systems. This paper is a review key issue of the Microgrids, islanding and protection of Micro grids.**

In general, a microgrid can operate in both the grid-connected mode and the islanded mode where the microgrid is interfaced to the main power system by a fast semiconductor switch called static switch, (SS). It is essential to protect a microgrid in both the grid-connected and the islanded modes of operation against all types of faults. Micro grids are becoming increasingly attractive to consumers and as such in the future, a great number of them will be installed at consumer's sites.

I. *MICROGRID CONCEPT*

Microgrid has two critical components, the static switch and the microsource. The static switch has the ability to autonomously island the microgrid from disturbances such as faults, other harmful events or power quality events. After islanding, the reconnection of the microgrid is achieved autonomously after the tripping event is no longer present. This synchronization is achieved by using the frequency difference between the islanded microgrid and the utility grid insuring a transient free operation without having to match frequency and phase angles at the connection point. Each microsource can seamlessly balance the power on the islanded microgrid using a power vs. frequency droop controller. This frequency droop also insures that the microgrid frequency is different from the grid frequency to facilitate reconnection to the utility. To enhance reliability, a peer-to-peer and plug-and-play model is used for each component of the microgrid. The peer-to-peer concept insures that there are no components, such as a master controller or central storage unit that is critical for operation of the microgrid. This implies that the microgrid can continue operating with loss of any component or generator. With one additional source, (N+1), we can insure complete functionality with the loss of any source. Plug-and-play implies that a unit can be placed at any point on the electrical system without

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reengineering the controls thereby reducing the chance for engineering errors. The plug-and-play model facilitates placing generators near the heat loads thereby allowing more effective use of waste heat without complex heat distribution systems such as steam and chilled water pipes. Peer-to-peer and plug-and-play concepts also impact the protection design. The peer-to-peer concept insures that there are no protection components, such as a master coordinator or communication system critical to the protection of the microgrid. Plug-and-play implies that a unit can be placed at any point on the electrical system without re-engineering the protection thereby reducing the chance for engineering errors. This implies that microgrid protection is part of each source.

II. INTRODUCTION

Interconnection of small, modular generation to low voltage distribution systems forms the Microgrid. Microgrids can be connected to the main power network or be operated autonomously, similar to power systems of physical islands.

Recently, Microgrids technology in small-scale distributed power generation system combined with power electronic system will produce the concept of the future network technologies. The main function of Microgrids is to ensure stable operation during faults and various network disturbances. Generally, microgrid is connected to the power delivery system at a point of common coupling, thus appearing as a controllable single subsystem to the utility grid. The microgrid concept enables high penetration of distributed generation without requiring re-design of the distribution system. Distributed generation and corresponding loads can be autonomously separated from the distribution system to isolate the microgrid's load from the disturbance during disturbances. It will intentionally disconnect when the quality of power from the grid falls below certain standard.

A micro grid is designed to seamlessly separate from the grid when problems in the utility grid arise, reconnecting again once these problems are resolved. Normally, in grid connected mode, the micro sources act as constant power sources, which are controlled to inject the demanded power into the network. In autonomous mode, micro sources are controlled to supply all the power needed by the local loads while maintaining the voltage and frequency within the acceptable operating limits. Autonomous operation is realized by opening the static switch, which disconnects the microgrid from the main grid as shown in Figure-1. Once the microgrid is isolated from the main grid, the microsources supplies to the system are responsible for maintaining the voltage and frequency while sharing the power.

The bidirectional power flow for both import and export of power is possible during grid-interconnected operation. In event of faults, isolation for microgrid as well as resynchronization is achievable for islanded operation. During islanding, each distributed generation unit is able to balance power and share loads within the microgrid system. The increased penetration of distributed generation in microgrid system may provide several technical problems in the operation of the grid, such as steady state and transient over or under-voltages at the point of connection, protection malfunctions, increase in short circuit levels and power quality problems. The control and protection of the microgrid as an autonomous system will also present challenging problems.

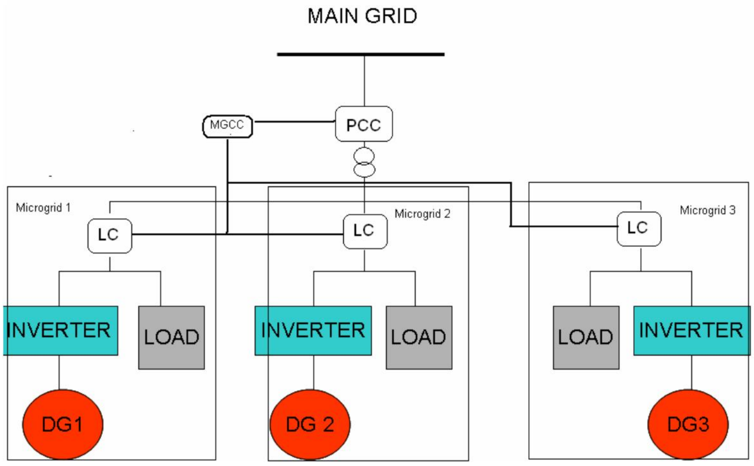

Fig 1. Microgrid architecture

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All grid-connected of microsources are required to have protection methods that cause the microsource to stop supplying power to the utility grid if the frequency or amplitude of the voltage at the point of common coupling between the customer and the utility within specified limits.

The protection methods protect consumers equipment but also serve as anti-islanding detection methods. Consider the configuration shown in Figure-2, in which power flow at the point of common coupling (PCC) between the utility and microsource. When the static switch is closed and the utility is connected, real and reactive power Pmic+ jQmic flows from the microsource to PCC, and power Pload + jQload flows from PCC to the load. Summing power flows at PCC,

Pgrid = Pload- Pmic

Qgrid = Qload-Qmic

This is the real and reactive power flowing into PCC from the utility. If the microsource operates with a unity power factor that is, the microsource output current is in phase with the voltage at PCC, then

Qmic=0 and Qgrid = Qload.

The behavior of the microgrid system at the time of utility disconnection will depend on Pgrid and Qgrid at the instant before the switch opens to form the island operation.

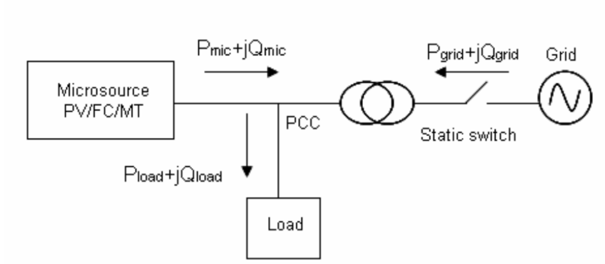

Fig-2.Microgrid power flow to utility grid.

Micrograds have been studied in several research projects. The technical challenge on microgrid is the control of the power flow and the network voltage by the power electronic converter. Most controllers that have been proposed are based on droop lines. During the transition from grid connected to islanded operation will cause large mismatches between microsource and loads, posing a frequency and voltage control problem

The microgrid advantages are as follows:

i) Provide good solution to supply power in case of an emergency and power shortage during power interruption in the main grid,

ii) Plug and play functionality is the features for switching to suitable mode of operation either grid connected or islanded operation, provide voltage and frequency protection during islanded operation and capability to resynchronize safely connect microgrid to the grid ,

iii) Can independently operate without connecting to the main distribution grid during islanding mode, all loads have to be supplied and shared by distributed generations. Microgrid allows integration of renewable energy generation such as photovoltaic, wind and fuel cell generations. Typical microgrid system comprises of distributed generation units with inverters and incorporate control systems that enable flexible operations.

The Microgrid concept assumes a cluster of loads and microsources operating as a single controllable system that provides both power and heat to its local area. This concept provides a new paradigm for defining the operation of distributed generation. To the utility the Microgrid can be thought of as a controlled cell of the power system. For example this cell could be controlled as a single dispatch able load, which can respond in seconds to meet the needs of the transmission system. To the customer the Microgrid can be designed to meet their special needs; such as, enhance local reliability, reduce feeder losses, support local voltages, provide increased efficiency through use waste heat, voltage sag correction or provide uninterruptible power supply functions to name a few. The microsources of special interest for Microgrids are small **(<100 kW)** units with power electronic interfaces. These sources, (typically micro turbines, PV panels, and fuel cells) are placed at customers' sites. They are low cost, low voltage and have high reliable with few emissions. Power electronics provide the control and flexibility required by the Microgrid concept. Correctly designed power electronics and controls insure that the Microgrid can meet its customers as well as the utilities needs.

Figure illustrates the basic Microgrid architecture. In this example the electrical system is assumed to be radial with three feeders A, B and C and a collection of loads. The radial system is connected to the distribution system through a separation device, usually a static switch. The feeder voltages at the loads are usually 480 volts or less. Feeder A indicates the presents of several microsources with one providing both power and heat. Each feeder has circuits' breakers and power flow controllers. Consider the power flow controller near the heat load in feeder A. This controller regulates feeder power flow at a level prescribed by the Energy Manager. As loads down stream change the local microsources increase or decrease their power output to hold the power flow constant. In this figure feeders A and C are assumed to have critical loads and include microsources, while feed B is assumed to have non-critical loads which can be shed when necessary. For example when there are power quality problems on the distribution system the Microgrid can island by using the separation device shown in the figure. The non-critical feeder can also be dropped using the breaker at B.

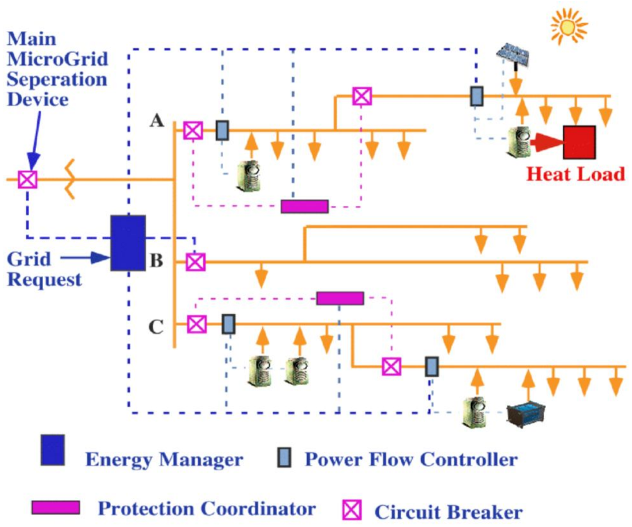

Fig-3. Microgrid structure with 3 feeders

A. System optimization

System optimization will be provided by the Energy manager unit in the power system. The Energy Manager uses information on local electrical and heat needs, power quality requirements, electricity and gas costs, wholesale/retail service needs, special grid needs, demand-side management requests, congestion levels, etc. to determine the amount of power that the Microgrid should draw from the distribution system. Some key functions of the Energy Manager are;

- Provide the individual power and voltage set point for each power flow/microsource controller
- Insure that heat and electrical loads are met
- Insure that the Microgrid satisfies operational contracts with the transmission system
- Minimizes emissions and system losses
- Maximize the operational efficiency of the microsources.
- Provides logic and control for islanding and reconnecting the Microgrid during events.

III. Description of The Micro-Grid Concept

A scalable, onsite power grid architecture is an aggregation of load, supply, and energy storage interconnections points (nodes), and controllers, networked along low voltage distribution feeders. This system provides a sustainable and seamless energy solution for the military installation to transition its power posture, during times of high peak power demand (peak shaving mode), other commercial power modes of operation (economic decision-making mode), and commercial power disruptions (islanding mode), resulting from natural or man-made events. This architecture facilitates onsite renewable power conditioning and routing to any section of the grid, at the discretion of the military commander. Some characteristics of a military micro-grid include:

A. Scalability

Micro-grids provide plug-and-play implementation of sustainable and renewable DG technologies, with reduction in fossil fuel consumption and associated air emissions, and enhanced use of the energy that is delivered to the power grid by these systems. The network control systems are sustainable and can scale up or down to fit the specific military operation, including utility grid-connected facilities, off-grid training areas, contingency operations such as forward operating bases and tactical operation centers, and reconstruction missions.

B. Adaptability

Micro-grids provide enhanced energy security for critical facilities during emergency operations, caused by equipment failure or human error on the local or regional grid, natural disaster, or deliberate sabotage or terrorist attack. This provides the military commander with the capability to dynamically load shed non-critical operations and strategically dispatch power wherever vital loads must be served at any point in time, without affecting grid stability.

C. Local Control

Micro-grids allow for rapid event response and adaptive control to accommodate time-intensive operations and digital power requirement loads that are sensitive to power quality disturbances (variations in sinusoidal waveform). This capability also mitigates potential instabilities that may result from high renewable power penetration on the installation’s distribution grid.

D. Energy Storage

During normal operating conditions, micro-grid control architecture uses economic decision criteria for directing power flows and to meet load demand, so that all power from the local DG assets is used most cost-effectively, whether to help limit peak utility demand or to store the energy for use later. During emergency operations, stored energy is used strategically with dynamic load shedding to maximize finite locally-stored power and fuel, and to enhance grid stability. This extends local energy availability and the number of days that the islanded systems can survive the commercial power outage.

E. Security, Reliability, and Sustainability

An intelligent micro-grid is a holistic approach to power generation, energy storage, distribution, and demand-side dynamic load shedding, based on decision criteria that are determined through critical mission decomposition and consequence modeling. Micro-grids enhance security, reliability, and sustainability, by reducing dependence on external power grids and energy supplies, though greater use of local renewable resources and optimization of the power delivered by conventional DG sources.

IV. Key Issues Of Microgrids

Technical benefits of the microgrid are an islanding implementation of distributed generation to improve the distribution system service quality and increased the power system reliability. Microgrid can be implemented to meet the increasing growth in demand and distributed generation is used to perform special task for microgrid operation such as reactive and active power control, ability to correct voltage sags and system imbalances. This section is a review of three technical challenges on micro grid with respect to voltage and frequency control, islanding and protection of micro grids.

V. Voltage And Frequency Control

In electricity system, active and reactive power generated has to be in balanced condition with the power consumed by the loads including the losses in the lines. The unbalance condition happens from power generated is not equal to the power demanded. The unbalanced between both by the kinetic energy of the rotating generators and motors connected to the system, causing a deviation of the system frequency from its set point value (50/60Hz). The purpose of voltage and frequency control is to ensure that the both voltage and

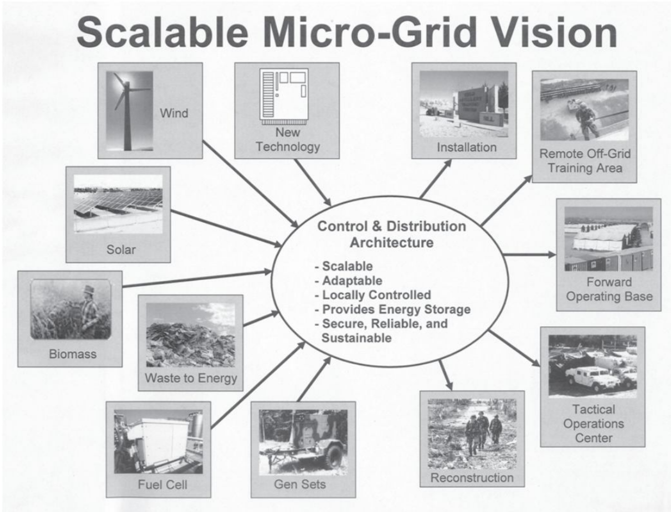

Fig-4.Scalable microgrid vision

frequency remain within predefined limit around the set point values by adjusting active and reactive power generated or consumed.

The connection of micro generation to Low Voltage networks is starting to deserve considerable attention from specialists worldwide, encouraging investigations and pilot experiences. In this context, a Microgrid concept has been developed under the framework of the Microgrids European Union project. A Microgrid can be defined as a low voltage distribution system to which small modular generation systems are connected. Generally, a Microgrid corresponds to an association of electrical loads and small generation systems through a low voltage distribution network. This means that loads and sources are physically close. Considering the currently available technologies, micro generation systems may include several types of devices such as fuel-cells, wind turbines or photovoltaic (PV) systems as well as micro turbines using either gas or bio-fuels. Apart from a low voltage distribution network, micro generators and electrical loads, a Microgrid must also include some kind of storage devices (such as batteries or flywheels) as well as network control and management systems. The storage devices will play an important role in this kind of Network, mainly in what concerns fast load-following situations. At the current research status, it is assumed that the Microgrid can be operated in two main situations:

Normal Interconnected Mode – the Microgrid will be electrically connected to the main network either being supplied by this network (totally or partially, depending on the generation allocation procedures adopted to operate the microsources) or injecting Power into the main grid (when the relation between the microsources installed capacity and the electrical loads allows this type of operation);

Emergency Mode – in case there is a failure in the main network, the Microgrid must have the ability to operate in an isolated mode, that is, to operate in an autonomous way, similar to the power systems of physical islands.

In operation of the microgrid, a challenging task is to operate more than one distributed generation on the island; it is no possible to use the active and reactive power control. It is necessary to regulate the voltage during microgrid operation by using a voltage versus reactive power droop controller for local reliability and stability. Each distributed generation is equipped with the power frequency droop characteristic during islanded operation. A dynamic analysis of generation control scheme consisting of active power-frequency and reactive power-voltage controllers for the inverter based distributed generations.

The fast and accurate voltage and frequency control are fundamental requirements for successful island operation of weak low voltage network based microgrid. The control of storage unit in microgrid is not enough to manage/restore voltage and frequency near the set values. Beside that, controllable loads and distributed generations (e.g. PV, fuel cells and micro turbines) would take part in voltage and frequency control according to their voltage and frequency droops. This is to enable the plug and play functionality of connection for distributed generations in distribution network.

The master slave approach was conducted to show the performance of a microgrid consisting of two types of distributed generations. The method proposed the output power of inverter based distributed generations are modified to compensate the new change in the microgrid system when the islanding occurs. The microgrid setting is adjusted in order to minimize the transient accruing when switching from grid connected to islanded operation. Inverted based distributed generations can provide the sufficient amount of reactive power to enhance the voltage quality and damping of oscillation occurring in the frequency work effectively.
The small-signal state-space model of autonomous operation of inverter-based microgrid is presented. Each distributed generation inverter has an outer power loop based using droop control to share the real and reactive powers with other distributed generations. Voltage and current controllers is used in inverter internal controls to reject high frequency disturbances and damp the output filter for prevent any resonance with external network.

VI. Islanding

Islanding is a small-scale representation of the future interconnected grid with a high density of distributed generations. The microgrid provides a benchmark between island and the interconnected grid. It is can be used in the large interconnected grid with the high penetration of distributed generation. The islanding control strategies are very important for the operation of a microgrid in autonomous mode. Two kinds of control strategies of islanding are used to operate an inverter. The PQ inverter control is used to supply a given active and reactive power set point and the voltage source inverter (VSI) control is controlled to feed the load with predefined values for voltage and frequency. The VSI real and active power output is defined by depending on the load conditions. Its act as a voltage source with the magnitude and frequency of the output voltage controlled through droop.

A new control strategy to microgrid in the distribution system

Two interface controls are for normal operation and the other control for islanded operation. An islanding detection algorithm was developed to responsible for switching between the interface controls. The islanding detection algorithm is to be efficient and can detect islanding even under load and DG capacity closely matching conditions.
The proposed control scheme is capable of maintaining both voltage and frequency within the standard permissible levels during islanded operation of the DG. Such control strategy could be used to supply critical loads in the distribution system during utility outage. Two possible control strategies developed in order to operate a microgrid under emergency mode. A sequence of actions for a well-succeeded black start procedure, involving microsource units has been identified for contributing an increase in distribution network reliability.

VII. Protection

"Micro grid protection" is the most important challenges facing the implementation of Microgrids. Once a microgrid is formed, it is important to assure the loads, lines and the distributed generations on the island are protected. The two alternative current limiting algorithms to prevent the flow of large line currents and protection of microgrid during utility-voltage sags. There are as resistance-inductance feed forward and flux-charge-model feedback algorithms, for use with a voltage-source inverter (VSI) connected in series between the microsource and utility grids.
The resistance-inductance algorithm function which was connected with the microsource and utility grids is to insert large virtual resistance-inductance impedance along the distribution feeder. As a result, the line currents and damp transient oscillations is limited with a finite amount of active power circulating through the series and shunt inverter. A new protection scheme has been introduced which uses the abc-dq transformation of the system voltage to detect the presence of a short circuit fault and by comparing measurements at different locations provides discrimination between faults in different zones of protection associated with a particular micro-grid network. This scheme avoids the complications caused by the variations in potential fault currents associated with utility connected and isolated operation of the micro-grid. It will provide a complimentary protection to conventional over-current relaying for scenarios, which produce significant fault currents.
A protection scheme based on directional is proposed for micro-grids consisting of over current synchronous based Distributed generations. Directional over current relays are used to protect the lines during both grid

connected operation and micro-grid operation. The relay coordination problem is formulated as a Mixed Integer Selective Nonlinear Programming problem and is solved using operation Particle Swarm Optimization (PSO). The directional over current relays are coordinated with each other to assure selectivity and reliability of the protection scheme. In addition, the protection of microgrid is very important to save the power network. The concept of protection is to have the same protection strategies for both grid connected and autonomous operation. Microgrid is interfaced to main power system by a fast static switch to protect a microgrid in both the modes of operation against all types of faults.

Protection must respond to both system and Microgrid faults. If the fault is on the utility grid, the desired response may be to isolate the Microgrid from the main utility as rapidly as necessary to protect the Microgrid loads. The speed of isolation is dependent on the specific customer's loads on the Microgrid. In some cases sag compensation can be used without separation from the distribution system to protect critical loads. If the fault is within the Microgrid, the protection coordinator detains the smallest possible section of the radial feeder to nullify the fault.

VIII. CONCLUSIONS

The three key or vital issues of technical challenges on micro grid with reference to voltage and frequency control, islanding and protection is discussed, that must be overcome by implementation microgrid effectively.

In this context, integration of small-scale generation in the form of Microgrids, supported by the application of power electronic converter, could potentially contribute to the improvements in service quality seen by end customers. In this power system configuration, the microgrid will be providing clear economic and environmental benefits compared to conventional type power system. Advancement of microgrid concept and technologies requires more effective to resolve numerous economic, commercial and technical challenges by close cooperation and exchange of information among researcher on these activities has highly beneficial for the advancement of the microgrid research.

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