Technical Issues and Challenges in Hybrid Microgrid Architectures

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Abstract : The distribution system is part of the electric power system that links the bulk transmission system and the individual customers. Increasing environmental concerns, consumer expectations in terms of reliability & better quality of power supply and improving economics of distributed energy resources (DER) based on renewable, is making Micro Grid a viable proposition. Present electrical distribution system offers many technical & operational glitches for successful integration of Micro Grid Technologies. Modern Power systems are smart, interconnected, interdependent, load sharing and phased mission systems. Micro grids are composed by distributed generators, energy storage devices, intelligent circuit breakers and local loads. In this paper, a review of the main micro grid architectures proposed in the literature has been carried out. The micro grid architectures are first classified regarding their AC or DC distribution buses. Besides, more complex micro grid architectures will be discussed. Both advantages and disadvantages of each one of the micro grid families will be discussed.

KEYWORDS: Reliability, Distributed Energy Resources, Micro Grid, Micro Turbine, Management, Challenges

I. INTRODUCTION

The concept of the micro grid was first proposed by the Consortium for Electric Reliability Technology Solutions (CERTS) in America; it is a new type of distributed generation network structure with a wide range of development prospects [3]. Micro grids comprise low-voltage distribution systems with distributed energy sources, storage devices, and controllable loads that are operated either islanded or connected to the main power grid in a controlled, coordinated way. The authors in [2-5] introduced the benefits of the micro grid, such as enhanced local reliability, reduced feeder losses, and local voltage support, providing increased efficiency using waste heat as combined heat and power, voltage sag correction, or providing uninterruptible power supply functions. The steady progress in the development of distributed power generation, such as hybrid micro grids and renewable energy technologies, are opening up new opportunities for the utilization of various energy resources.

A Microgrid, a local energy network, offers integration of distributed energy resources (DER) with local elastic loads, which can operate in parallel with the grid or in an intentional island mode to provide a customized level of high reliability and resilience to grid disturbances. This advanced, integrated distribution system addresses the need for application in locations with electric supply and/or delivery constraints, in remote sites, and for protection of critical loads and economically sensitive development. (Myles, et al. 2011).

A Micro grid is any small or local electric power system that is independent of the bulk electric power network. For example, it can be a combined heat and power system based on a natural gas combustion engine (which cogenerates electricity and hot water or steam from water used to cool the natural gas turbine), or diesel generators, renewable energy, or fuel cells. A Micro grid can be used to serve the electricity needs of data centers, colleges, hospitals, factories, military bases, or entire communities (i.e., “village power”)(Campbell 2012).

A true Micro grid is much more than a backup power system, however, even if it also does that as one of its core functions. It also has to include real-time, on-site controls to match the Micro grid’s generation and storage capacity to power use in real time, as well as have some way to interact with the grid.” (St. John 2012).

Micro Grid can be realized through utilizing the potential of distributed renewable energy resources where various small power systems working as independent “Micro Grids” may be established which can cater to several consumers’ loads through small size distributed energy resources. In other means, Micro grids are modern, small-scale version of centralized electricity systems which generates, distributes and regulates the flow of electricity to a set of consumers at the local level itself. From generation point of view, with the advancement of renewable generation technologies, small generating units exploiting renewable sources through Solar PV panels, wind turbines or biomass plants have already been commercialized at distribution level. However, at most of the places Micro Grids are realized through Single resources generation like Solar PV along with Battery Storage systems.

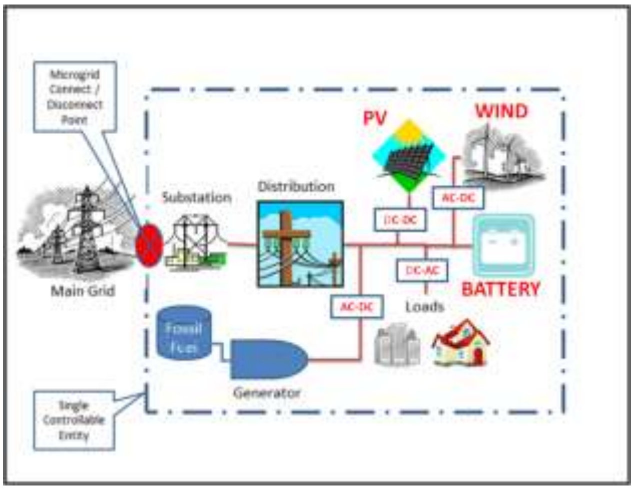

Figure 1 Elementary Micro Grid Architecture

II. RESOURCES OF HYBRID MICRO GRID

The hybrid Micro grid may consist of Solar Photovoltaic array (PV), Wind turbine (WT), Biomass Gassifier (BG) and Battery Energy Storage (BES). In grid-interfaced Hybrid Micro grid architecture systems, two types of control i.e. sources control and load control should be designed. Source control is achieved primarily through generation control of Biomass Gassifier or Battery energy storage systems which serves as flexible generation whereas Solar PV and Wind, considering its nature of resources, is never controlled or backed down. At the time of supply exceeding demand, flexible resources like Biomass is asked to back down/shut down and balance excess energy is used to charge the batteries for utilization in times of lower generation by other resources like Wind/Solar. Thus energy storage batteries provide an economical and/or logistical advantage by making better use of off-peak hours to supply the daily energy needs in peak hours. In case of demand exceeding the generation, batteries provide immediate power response dynamically to the net load fluctuations as Biomass Gassifier gives comparatively slower responses, but longer duration support. In real terms, design of Micro grid should be based on self-sufficiency criterion that means in normal scenario, energy is not drawn from the main grid.

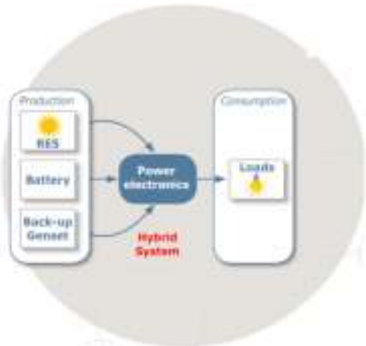

Figure 2 Concept of a Hybrid Micro grid with Renewable Sources

As the renewable resources generally suffers with the limitations of intermittency and variability, use of more than one distributed resource i.e. resource diversity, improves reliability and security of power supply. Thus hybrid Micro grid system is preferred over the use of single resource Micro grid System, but challenge lies in integration of all such resources based generations to meet consumer demand with reliability, security and best of quality.

The power generated by a PV system and wind turbine [6] is highly dependent on the weather conditions. Batteries are used as a long-term energy storage system to use solar and wind energy resources more efficiently and economically [8]. Ultra Capacitors (UCs) as short-term energy storage are used to compensate for transient conditions because they can be charged and recharged rapidly in the condition of uncertainty and sudden interruption.

The distributed generators (DG) in Micro grid are generally inverter-based that has very low inertia. Unlike, rotating DGs, the low inertial inverter based DGs have tendency to respond very quickly causing large transients. These transients of high magnitude are not favorable for stable operation of Micro grid. However, due to their fast response, the inverter based sources ensure the supply of dynamic load regardless of slow rotating machines which requires seconds of response time to transients [11]. Therefore, this aspect needs to be taken care while designing architecture of Micro grid.

III. MICRO GRID TAXONOMY

A. Key features of a Micro Grid

According to the sources examined, the key features of a Micro grid include:

- Operation in both island mode or grid-connected
- Presentation to the Macro grid as a single controlled entity
- Combination of interconnected loads and co-located power generation sources
- Provision of varied levels of power quality and reliability for end-uses, and
- Designed to accommodate total system energy requirements

B. Types of Micro Grids

The Research has identified five key types of Micro Grids or market segments where Micro Grids would best apply (Asmus and Stimmel, Utility Distribution Micro grids 2012). These key Micro Grid categories include the following:

1. Campus Environment/Institutional Micro Grids

The focus of campus Micro grids is aggregating existing on-site generation with multiple loads that are co-located in a campus or institutional setting (e.g., industrial park). Scale ranges from 4 Megawatts (MW) to more than 40 MW.

2. Remote "Off-grid" Micro Grids

These Micro grids never connect to the Macro grid and instead operate in an island mode at all times. Examples of this type of Micro grid include the remote village power systems on islands that usually include diesel power or wind generation. Micro grid is being developed with the goal of reducing diesel fuel by integrating solar Photovoltaic (PV), distributed wind, and/or run-of-the river hydropower.

3. Military Base Micro Grids

These Micro grids are being actively deployed with focus on both physical and cyber security for military facilities in order to assure reliable power without relying on the Macro Grid. This segment also includes mobile Military Micro grids for forward operating bases.

4. Commercial and Industrial (C&I) Micro Grids

These types of Micro grids are maturing quickly in various countries; however, the lack of well known standards for these types of Micro grids limits them globally. Therefore they are a "type" of Micro grid but without clear characteristics.

5. Community/Utility Micro Grids

These deployments do not meet the classic definition of a Micro grid because they do not "island."

C. Need of Micro Grids (Drivers of Micro Grids)

- Micro grid advocates that reliability and power quality can be dramatically improved at the local distribution level through systematic application of Micro grid technologies.
- To meet local demand (49% of respondents)
- To enhance grid reliability (36%)
- To ensure local control of supply (30%). Lower frequency responses included enhancing supply reliability, reducing energy cost and enhancing grid security.
- Micro grid as a foundational building block in the ultimate smart grid
- Micro grid provides reliability and integration of distributed energy resources (DER) and energy storage assets through improved system intelligence
- To reduce the physical vulnerabilities of the electric grid during natural disasters

D. Micro Grid-enabling Technologies

The key capability and feature of a Micro grid is its ability to island itself from a utility's distribution system during blackouts. However, in order to have an operational Micro grid that can perform in the manner expected – both online and islanded – requires use of the following technologies:

- Distributed Generation (DG)
- Islanding and Bi-Directional Inverters
- Smart Meters
- Distribution Automation (DA)
- Substation Automation
- Smart Transfer Switches
- Advanced Energy Storage
- Micro grid Control Systems
- Energy management systems
- Distribution management systems
- Communication technologies and sensors.

E. Pros and Cons of Micro grids

- From the electric grid's perspective, the primary advantage of a Micro grid is that it can operate as a single collective load within the power system.
- Customers benefit from the quality of power produced and the enhanced reliability versus relying solely on the grid for power.
- Distributed power production using smaller generating systems – such as small-scale combined heat and power (CHP), small-scale renewable energy resources can yield energy efficiency and therefore environmental advantages over large, central generation.
- Blackouts and power disturbances are either eliminated or substantially minimized.

- Economically the Micro grid's improved reliability can significantly reduce costs incurred by consumers and businesses due to power outages, brownouts, and poor power quality.
- Micro grids can also generate revenue for constituent consumers and businesses by selling the Micro grid power back to the grid/utility when not islanded.
- Micro grids have the flexibility needed to use a wider range of energy sources such as wind, solar, fuel cells, etc
- Energy storage options and capabilities are a very weak link in the success of Micro grid operations

IV. HYBRID MICRO GRID ARCHITECTURES

According to the micro-grid design principles proposed in literature, there are three hybrid AC/DC micro-grid architectures:

AC MICRO GRID

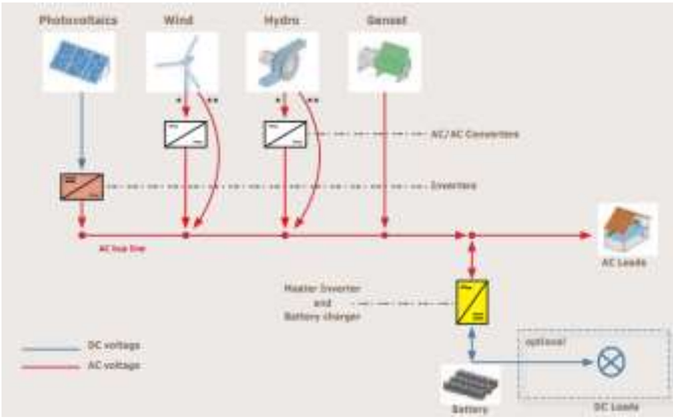

Figure 3 AC Micro Grid Architecture

AC micro grid is currently the main form, and radiation type is the basic structure. According to the application of micro grid, load type and capacity size, the AC micro grid is divided into three categories: system level micro grid, commercial and industrial micro grid, as well as rural micro grid. Figure 3 shows an AC micro grid structure.

DC MICRO GRID

Recently the number of DC loads has been increased and urban distribution grid has been developed. In addition, DC micro grid does not exist the problems which AC micro grid has, such as voltage, frequency and synchronization problem. As a result, DC micro grid has been developed rapidly. According to the different quality requirements for electricity, there have been several typical DC grid structures in recent years, such as ring type, radiation type, feeder type, etc. Figure 4 shows a DC micro grid structure.

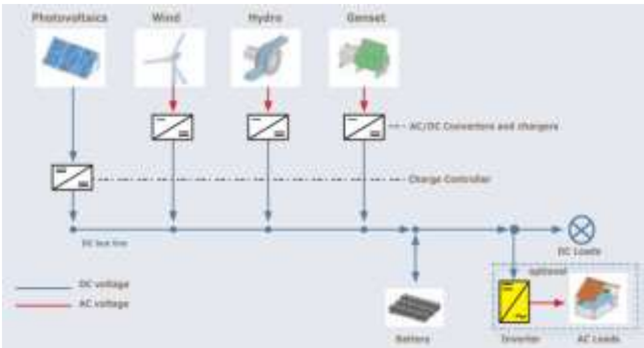

Figure 4 DC Micro Grid Architecture

In Figure 5, the trunk lines adopt the DC bus completely in the micro grid, so the distributed generation and AC/DC loads can access to the DC bus through the power electronic converter, and then DC micro grid can be connected with the large systems through the bi-directional converters. Small low voltage DC micro grid accesses to the medium voltage DC bus voltage via the DC transformer. The advantage of the ring structure is of high reliability of supply, while the disadvantages are that the fault is hard to identify and protection control system is relatively difficult to design.

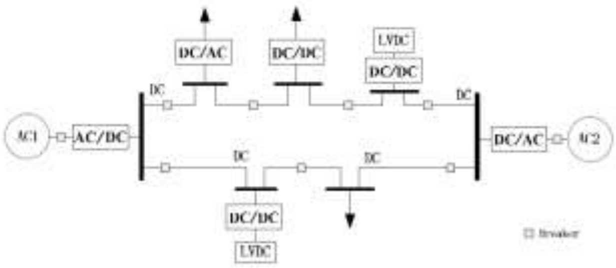

Figure 5 Ring type DC Micro Grid Structure

Figure 6 shows the radiation type of DC micro grid, which is connected to the AC distribution network through a bidirectional converter. Each distributed generation and loads are connected to a DC bus directly or indirectly, and then buses with different voltage level are connected together through the DC transformer. The disadvantage of the radial structure is low reliability of power supply, while the advantage is that the ability of fault identification is reliable and the design of the protection system is relatively easy.

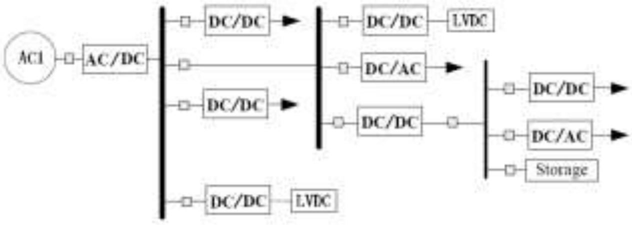

Figure 6 Radial type DC Micro Grid Structure

Figure 7 shows the feeder type structure of micro grid. Compared with the ring type, there is only one bi-directional converter which connects the micro grid with distribution network. This type of micro grid is suitable for rural and other remote areas, and its advantages are as follows: system design is simple, the control system is relatively simple than the ring and radiation type, besides, and fault identification and protection is relatively simple. The disadvantage is of low reliability of power supply.

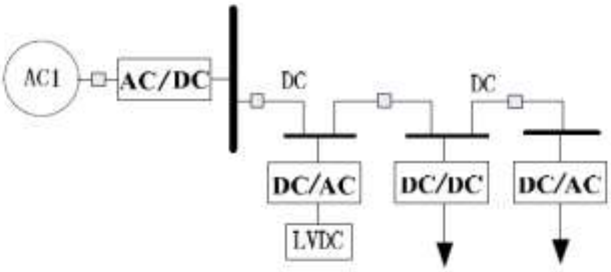

Figure 7 Feeder type DC Micro Grid Structure

AC-DC MICRO GRID ARCHITECTURE

Figure 8 shows an AC-DC micro grid structure. The distributed generation and AC/DC loads can access to the DC bus through the power electronic converter, and then AC micro grid can be connected with the large systems through the transformers. A new AC-DC hybrid micro grid structure is the ideal choice. Using the AC-DC hybrid micro-grid, the power supply will meet the reliability, economy and flexibility requirements.

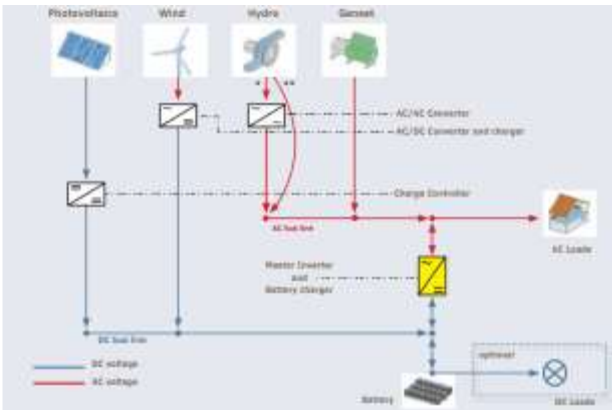

Figure 8 AC-DC Micro Grid Architecture

There are a number of internal inductive loads in AC-DC micro grid, such as transformers, and asynchronous motors. Also there are a large number of micro grid power electronic devices (such as rectifiers, inverters, chopper circuits), and these nonlinear devices need to consume large amounts of reactive power, while these devices will generate a lot of harmonics, and which need to absorb some reactive power as well. Therefore, in the internal of the micro-grid, it must be configured reasonably static or dynamic reactive power compensation devices [12-15].

PROPOSED AC-DC MICRO GRID ARCHITECTURE

The research of AC and DC micro grid topology has been more mature, but still less for AC-DC hybrid micro grid topology research literature. In [15], an AC-DC hybrid micro grid structure is presented. In figure 5, the micro grid consists of two parts, AC part is connected with DC part through a bidirectional converter, and then the AC bus is connected with the distribution network through a transformer. AC and DC load access to micro grid through appropriate power electronics devices respectively. The system can run on a variety of operating status by controlling the bi-directional converter and isolating switch at the PCC, such as: a) grid connected operating status; b) AC parts operate on grid connected status, while the DC parts operate on islanding status, and the bi-directional converter stays off; c) AC and DC part operate on the islanding status, PCC at isolating switch off; d) AC and DC parts operate independent, and isolating switch off at PCC1 while the bi-directional converter turn off at the same time.

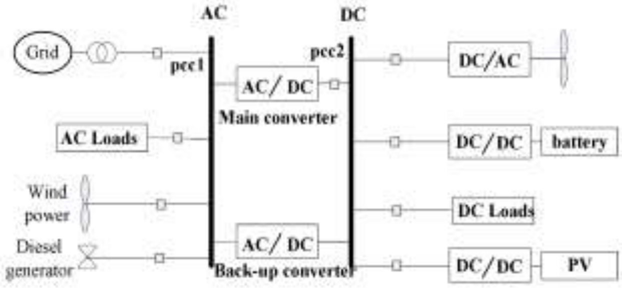

Figure 9 Proposed Hybrid AC-DC Micro Grid Architecture-1

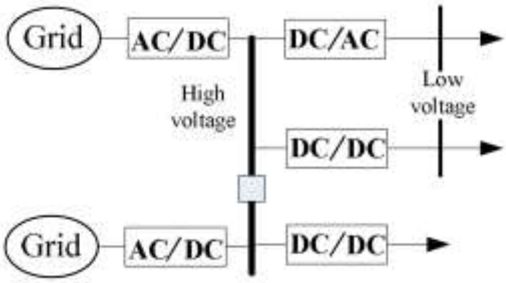

Figure 10 Proposed Hybrid AC-DC Micro Grid Architecture-2

According to the proposed design principles of the micro grid, we analyze the structure-1. The system AC and DC micro grid are in two separate areas, the AC power supply and AC load combine together, while the DC power supply and DC load combine together, and the two micro grids are connected via converters. The hybrid micro grid is connected with the distribution network, and the PCC is set at the AC bus, which reflects the principle of partition. There are two different AC and DC bus voltage levels in the System, which also reflects the hierarchical design principles. In addition, the important load equipped with energy storage devices, in case of an emergency operation.

Figure 10 is an AC-DC hybrid micro grid design example of an industrial park. The micro grid connects with the 11kV AC grid through the converter, and the system adopts the high voltage DC bus as the main frame work and together with the low voltage AC and DC link bus as a supplement to it. The high voltage DC bus is connected to the low voltage DC bus through a DC/DC converter, which reflects the hierarchical design principles, meaning that micro grid should set different voltage levels. AC power and load are connected to the low voltage AC bus through the feeder, while DC power and the load are connected to the low voltage and high voltage through the feeder, which reflects the partition principles.

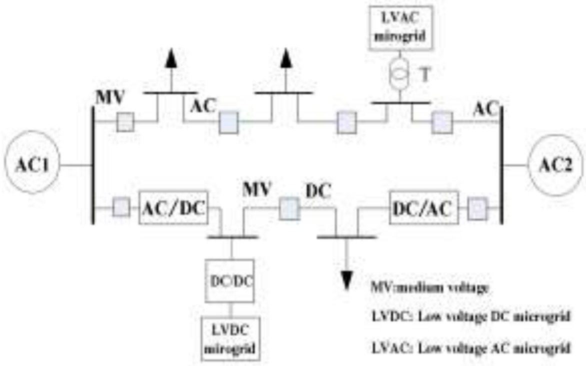

Figure 11 Hybrid AC-DC Complementary ring Architecture

The complementary ring structure is shown in Figure 11. According to it, there exists AC micro grid and DC micro grid together in the distribution networks and the medium voltage DC bus is connected with the AC distribution networks through a bi-directional converter In addition, the low voltage AC micro grid is connected with the medium voltage AC bus through the step up/down transformer. The AC/DC hybrid complementary structure can greatly improve the reliability of power supply. Compared with the pure DC micro-grid and AC micro grid, using the AC/DC hybrid approach, can save a lot of AC / DC converters and reduce the investment as well.

In addition, compared with the ring type DC micro grid (Figure 5), hybrid complementary ring structure can reduce AC/DC inverter capacity. With much higher reliability of power supply compared to the ring type distribution network, while fault handling capability can be greatly enhanced. If the main AC / DC converter fails, DC micro-grid can be easy to form an island. Due to the lack of internal micro-grid power, some of the loads have to be removed, resulting in a certain impact on the user. Yet AC/DC hybrid micro-grid does not affect the operation of the AC micro-grid when both sides of the AC / DC converter fails, hence increasing the power supply reliability. In terms of fault identification and protection control, the AC part can adopt the proven equipment, and reduce investment.

TECHNICAL AND OPERATIONAL CHALLENGES

A. Operation support in Grid tied and islanded conditions

In grid-tied condition, the DG has to work in PQ mode where the source controller of DG controls the output current. In this condition, Voltage and frequency of Micro grid is governed by grid parameters and therefore DGs have to follow the Superior Grid. In islanded condition, when the Micro grid is in isolated state from the utility grid, DG has to transition in PV mode controlling Voltage &

frequency of its own autonomous mode. In hybrid system, where more than one DG is present, all DGs are operated in parallel in master-slave configuration. A Micro grid following master-slave strategy needs only one energy source to operate in PV mode when utility grid is absent.

B. Black start capability

Black start phenomenon is to start the Micro grid system from complete shutdown state. It is a challenging task to black start a Micro grid system because it requires complete analysis of system's state. Moreover start of DGs and connection of loads requires certain procedure to be followed. It involves step-by-step connection of DGs and loads to the LV grid on the basis of overload capacity. However, in comparison to conventional power restoration, the Micro grid restoration process is much simpler due to reduced number of variables (switches, DGs, and loads) [6]. The capability of black start is most needed in remote areas where utility grid is absent and where utility grid outages are very frequent. In Micro grid system, bottom-up approach to black start is more preferred as it reduces the restoration times [6].

C. Protection strategy

The protection scheme of Micro grid is much more complex and challenging than conventional power system because of the requirements of both grid-interfaced and grid-isolated modes in Micro grid and also, the existence of the two types of faults - internal and external faults.

D. Number of customers served

E. Full time or part time micro-grid?

F. Physical length of circuits and types of loads to be served

G. Voltage levels to be used

H. Feeder configuration (looped / networked / radial)

I. Types of distributed generation utilized

J. AC or DC micro-grid

K. Heat-recovery options

L. Desired power quality and reliability levels

M. Methods of control and protection

N. Selection of generating technologies

- Internal combustion engines (10 kW to 10 MW)
- Mini to small-size combustion turbines (0.5 to 50 MW)
- Micro turbines (20 to 500 kW)
- Fuel cells (1 kW-10 MW)
- Photovoltaic systems (5 W to 5 MW)
- Wind turbines (30 W to 10 MW)

O. Ideal micro-grid generation technologies will have the following characteristics:

- Modular design (scalable from 1 kW up to 10 MW)
- Low capital cost (preferably much less than $1000/kW installed)
- Low operation and maintenance cost
- Suitable for residential, commercial, and industrial permitting constraints
- Low emissions (meet or exceed those of large modern fuel fired power plants)
- High efficiency over broad range of loading conditions (at least 40%)
- Usable waste heat (higher exhaust temperature is better)
- High power quality (low harmonics, good voltage and frequency regulation)
- Good load-following characteristics (for large load steps and transient motor starts)
- Rapid start up (from cold start and standby conditions)
- Good energy density (high power/weight and high power relative to footprint area required)
- High reliability and dispatchability
- Resistant to damage by power system voltage and current anomalies (surges, voltage unbalances, and so on)
- Operate on fuel that can be easily delivered or transported to the site
- A mature technology with excellent support infrastructure

V. COMPARISON OF HYID MICROGRIDS WITH TRADITIONAL POWER SYSTEM APPROACHES

In making this comparison, some key areas that are clearly important include:

- Cost
- Efficiency
- Reliability
- Potential for ancillary services

1. Costs of Integrated Micro-Grid Systems Compared to Traditional T&D Systems

In comparing the cost of micro-grid systems to conventional T&D systems, it is important to analyze the components that make up the cost of energy delivered via the traditional bulk power system and compare those to the costs of energy delivered via micro-grids. The cost elements of the traditional power system include the bulk generation, transmission, sub-transmission, distribution substation, primary feeder, and secondary system. For a micro-grid, the cost is the distributed generation cost added to the cost of the power system that makes up the micro-grid. If it is a low-voltage micro-grid, the only cost is basically that of the low- voltage wiring infrastructure with all of its controls and protection. There is no high-voltage infrastructure. Figure 12 is an example showing a hypothetical comparison between a utility grid and Micro Grid delivering same amount of power.

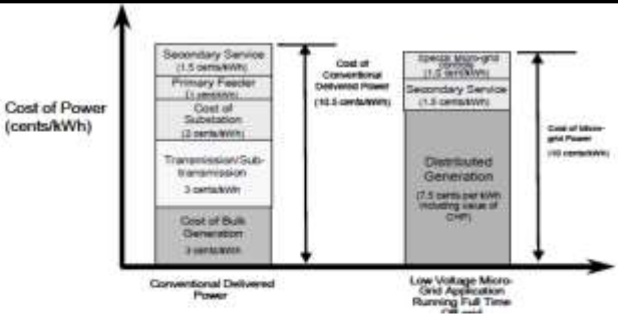

Figure 12 Cost comparisons of utility and micro grids

2. Efficiency of Micro-Grid Systems

There are two sides to the distributed generation and micro-grid efficiency argument. One school of thought considers that distributed generation is extremely efficient compared to the bulk utility system, and the other school considers that it is less efficient than a current central-station power plant. The efficiency of distributed generation can certainly be greater than the bulk power system, but it is important to recognize that this is not universally guaranteed for all applications, many applications are less efficient when they do not employ the correct elements needed for efficiency success.

3. Reliability of Micro-Grid Compared to Conventional Power

The reliability of average power distribution circuits in the United States is about 99.98%, which means that power is available for 99.98% of the year or there are about 2 hours of cumulative interruption time each year. This is far better than typical individual distributed generators such as ICE units or CT units, which have availability in the range of 95 to 98%, depending on how they are maintained and operated. To achieve 99.98% with ICE units requires more than one unit, and they need to be sized so that if one should fail, the others can pick up the load.

4. Potential for Ancillary Services

Micro-grids offer the potential for two key ancillary services that may be able to generate a revenue stream for the owners/operators of the micro grid. The two key ancillary services are: Thermal energy and Reliability. These services really cannot be offered with a conventional power system because generation is located a long-distance from loads and because it is very difficult to have targeted high-power quality/reliability on the conventional system. So these are service areas where the micro-grid with distributed generation really has an advantage over a conventional power system.

VI. CONCLUSION

This paper investigates technical & operational challenges and probable solutions for Hybrid Micro grid systems comprising various distributed energy resources. Micro grid appears to be an opportunity for continued study, expanded pilots and demonstration projects and ultimately to more common deployment. Hybrid Micro grid architectures operation of a system based on renewable power generation units is presented in this paper. The system challenges and technical issues involved with operational aspects in micro-grid scheme are identified and discussed.

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