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Operational Frameworks for Utility Integrated Microgrids

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SUMMARY

This paper provides an overview of the operational, planning, and control framework required for a utility-integrated community-based microgrid. Design, planning, and operational requirements are reviewed along with microgrid control hierarchy and technology enablers. Special focus is given to the integration of the microgrid with the utility grid system and how utilities can leverage microgrids to complement existing utility grids and customers.

The first part of the paper describes the various tasks involved in the design, engineering, and implementation of a utility microgrid project. The second part of the paper outlines the common operating practices and the challenges in control and protection system development for a microgrid. The third part of the paper describes microgrid functional requirements, emerging technologies, and the integration of the microgrid with the utility grid.

KEYWORDS
Microgrids, Smart Grid, Distributed Generation, Distribution Automation, Microgrid Controller, Integrated Grid

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Introduction

Microgrid has recently attracted a lot of interest among utilities and regulatory groups. However, design of a microgrid for a utility environment requires a much deeper dive into the planning and operational aspects of distribution systems.

The focus of this paper will be on utility-integrated microgrids. A utility-integrated microgrid will have the ability to run in parallel with or in isolation from the existing utility grid, and transition between these modes of operation. There are many existing microgrids in operation today that run in parallel with utility grids but very few can island and transition between these modes of operation. This requirement adds additional complexity to the design and implementation of the utility-integrated microgrid. These operational challenges and considerations will be evaluated in later sections of this paper.

The first step in the planning process is to identify the goals and objectives for the utility-scale microgrid project. While utility-scale microgrid technology can be applied at the transmission and distribution system levels, this paper will focus on partial distribution feeder designs that target a group of customers within a defined footprint. This type of microgrid is usually referred to as a community-based microgrid. The goals and objectives for these types of applications are focused on improving reliability and resiliency, enabling renewable generation, enhancing efficiency, and the economic dispatch of distributed generation for participation in the ancillary power markets.

The first challenge in the planning process is to develop selection criteria that reflect the project goals and objectives. Many utilities are focusing on applications that have the ability to benefit a large number of public-purpose customers. The primary objective of this type of design is to maintain service to customers that have the ability to provide critical public services in the surrounding areas, in the event of a long duration outage caused by a large storm event. The challenge with this type of design is to identify target areas that have a high concentration of public purpose/public service providers, have reliability and capacity challenges, and can be easily reconfigured to operate in islanded mode by establishing a common point of interconnection (POI) with the existing utility grid.

To gain a better perspective regarding the electrical reconfiguration challenge, one must first evaluate the unique system and customer attributes such as existing circuits and voltages, customer supply voltages, and local area utility grid configuration for each potential project. Each utility distribution system area will have its own unique attributes and topography. Many distribution system networks in mature metropolitan areas have evolved over many years. The evolution of these networks has been driven primarily by population, load growth, and technology changes over the years. As a result, many areas within these distribution networks are overlaid with many circuits of increasing voltage that reflect the load growth and technology changes. While this existing circuit topography provides customers with increased reliability and resiliency advantages, primarily through conventional distribution automation, it usually makes circuit reconfiguration for a partial feeder microgrid with a common POI a challenge. Partial feeder microgrids are designed to maintain service to customers within a small geographic area that is fed from a larger feeder or multiple feeders. This is accomplished by installing local generation with a common POI with the existing utility grid.

Many high potential projects will be identified and evaluated during the selection process. A project that appears to have high potential, when viewed at a high level, might not be feasible when the existing electrical configuration is considered and evaluated. An ideal project would have all customers connected to a single radial underground feeder that ends at the last customer to be included in the microgrid. This configuration allows for the creation of a common POI at a minimal cost and effort. In addition, the underground construction eliminates the need to storm-harden existing aerial facilities that are susceptible to storm damage within the microgrid footprint.

Unfortunately, this ideal configuration is rarely the case in existing distribution systems. Many areas within existing utility territories will require a significant amount of hardening and reconfiguration work to establish a hardened microgrid with a common POI. The varying amounts of complexity and cost have a large impact on cost and feasibility of a project, which will usually result in multiple design iterations to further re-evaluate customer mix and microgrid size for managing the cost against expected value propositions. Most high potential areas in metropolitan areas are fed from different circuits at various voltage levels with target customers connected to multiple circuits that are interconnected with distribution automation schemes. In addition, these circuits will have a varying mix of aerial open wire, aerial cable, and underground facilities. All of these variables will result in different amounts of reconfiguration and hardening work required to establish a viable microgrid. Increasing amounts of electrical reconfiguration will decrease the feasibility and, in some cases, eliminate projects from further consideration. Therefore, a time consuming iterative process will be required to identify, flush out, and evaluate high-potential conceptual designs. These high-potential conceptual designs will need to be refined and evaluated to determine benefits, performance improvements, costs, optimal design configuration, and operating capabilities. This is accomplished by conducting feasibility studies and business case evaluations for proposed conceptual designs. [1]

Project Life Cycle

Proper design of a microgrid system encompasses several aspects such as system topology, demand profile and boundary, customer selection, generation technology selection, generation location and sizing, business considerations, potential future development, communication infrastructure, and control/protection system methodology. Because all these aspects are heavily influenced by the target objectives and goals, it is essential to determine the design objectives and expectations prior to embarking on a design.

Due to the varying levels of complexities for desired system and operational characteristics of utility-scale microgrids, the system planning and design stages are best approached from a systems engineering perspective, as a minimum. The pivotal principles of systemic thinking helps to ensure successful realization of the system design objective(s), which employs the following top-down life-cycle based process beginning from identified need to final commissioned system. The phases include; conceptual design, preliminary design, engineering and development, construction, and operational use and system support phases. Figure 1 shows different stages of each phase.

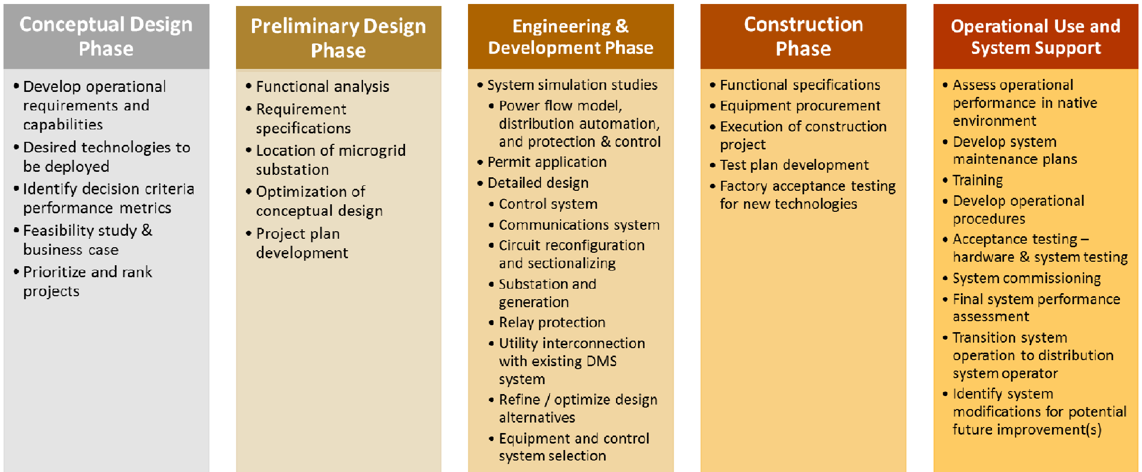

Figure 1 - System Planning, Design and Deployment Stages

As one would suspect, different design objectives will yield different outcomes for each of the milestones listed above. With this in mind, the design objective is recommended to be established early and static throughout the process to maintain a "hard" system. A dynamic design objective will create a "soft" system with an apparently unclear objective, therefore leading to unstable requirements analyses, their allocation, associated requirement specifications, etc. Although there are many possibilities of design objectives for utility-scale microgrids, the core components of the design objective for most microgrid projects are to increase resiliency against power outages, provide critical load support, improve efficiency, and decrease green-house gas emission.

Microgrid Load Profile Analysis

Traditional Load Analysis

One of the many important considerations for achieving an effective microgrid design capable of providing adequate support entails a detailed loading analysis of the footprint itself. Loading analyses are not a new concept to the utility world, but the methods required for proper microgrid asset selection, location, and load management will require the adoption of new perspectives by the utility, particularly in the distribution realm.

Traditionally, load analysis by most electric utilities entails the utilization of available real-time and/or historical amps, real power (P), reactive power (Q), and other available system readings as measured from the distribution primary voltage feeder-level distribution automation devices (if employed) and substation breakers & above. These measurements, which provide the visibility needed to verify adequate facilities and optimal steady-state system configurations, are present to support the current or forecasted annual peak load condition(s) without violating specific system parameters such as operating flexibility, contingency loading, adherence to required service voltage band limits, etc. All the previously mentioned conditions must hold true for the utility-integrated microgrid as well, which introduces significant challenges to the utility. The challenges arise primarily from the expected limited available generation capacity in comparison to the larger capacity area utility substation. Limited real and reactive power support when in islanded mode within the microgrid necessitates the increased granularity of loading visibility and analysis down to a minimum of the service transformer level, and perhaps to the customer-level dependent upon the system design and desired objectives.

Demand Data Granularity

In order to achieve the level of granularity required to effectively select and utilize the generation assets to be installed, transformer loading data must be readily available. Many utilities have progressed into this area in recent years as a result of other smart grid related initiatives that included the replacement of previous metering technologies such as AMR[1] meters with 60-minute kWh resolution with newer AMI[2] meters. These meters have varying capabilities dependent upon the manufacturer, but most provide voltage and kWh measurements with increased frequency when compared to AMR meters with typical 15- or 30-minunte kWh resolution available.

Degree of Loading Analysis

Typically, the extent of which you perform the microgrid footprint loading analysis will to a degree be dictated by the overall defined operational objectives of the microgrid and the generation asset types selected for deployment. Approaches to the selection of the generation asset types could be viewed as the following:

- Types of generation assets are selected to satisfy non load-dependent criteria such as required percentage of renewable generation mix/penetration level, available state and federal subsidies for PV installations, local regulatory-based restrictions or alternate generation initiatives (i.e. – CHP), etc.
- Allowing load-dependent criteria to become the drivers for generation type selection, which include, but not limited to, peak load and voltage support capabilities, required demand response characteristics for black start capability, time-series load-to-generation matching, etc.
- Combination of load-dependent and non-load dependent criterion

Once generation assets are selected pursuant with the desired criteria, the loading analysis should follow in support of assessing adequacy of the assets' capabilities to support the load during all modes of intended operation. This will also be crucial in the process of designing the load sectionlization scheme within the microgrid, which serves the dual-purposes of fault isolation as well as load restoration and load shedding management during contingencies.

Time-Series Loading Analysis

Due to the loss of near infinite P and Q supply available to the distribution level, partial-feeder microgrid footprint when in grid connected mode, a time-series assessment of the P and Q demands of all loads (minimum to the service transformer level) needs to be conducted. The time-series analysis throughout the course of a representative timeframe of interest (minimum of one (1) full year recommended) will reveal potential system design or operational deficiencies, as well as allow for categorization of time/season dependent load profiles for generation optimization if desired. These minimum 8760 demand data values are then best utilized when imported into a representative load flow model, which includes the

[1] Automatic Meter Reading
[2] Advanced Metering Infrastructure

microgrid substation transformer(s), proposed generation assets with interconnecting transformers, existing service transformers to be supported, existing and new conductor infrastructure within the footprint, external "macrogrid" feeder interconnecting into microgrid, and any other pertinent system elements that could affect the load and voltage profile of the system.

Within this comprehensive form of loading analysis, maximum and minimum slopes of load ramp-rates, seasonal sensitivities, and magnitude of time-variation over a 24-hour period, and any other impactful system dependent variables should be evaluated. Load aspects such as these will be crucial when selecting types, and even particular models of generation assets that provide the necessary response to transient load changes. For example, fuel cell installations are known for their base load applications, and would be best utilized installed near a fairly constant demand in an uninterruptible service application. An alternate scenario could involve the decision between selecting a diesel or natural gas synchronous generator based on the required load-ramp capabilities of each, depending upon whether or not seamless transition from grid-connected to island mode is a design objective. Also if the power flow model reveals that there may be sub-hour periods where the "nodal" load section may exceed a generator's ramp-up capabilities, sub-divisions of a load section may be required via further sectionalizing. In summary, many aspects of the design characteristics and microgrid generation type selections will be affected by a proper load profile analysis, and will become increasingly important in direct correlation with higher environmentally dependent renewable system penetrations and stricter generation optimization standards.

Operating Strategies

Proper system design and operating procedures play an important role in the definition of microgrid control requirements, particularly with proliferation of DERs and utilization of emerging technologies. Figure 2 shows an overall view of different operation stages to be considered throughout the development of microgrid operating strategies. The stages shown in Figure 2 are the main technical requirements that are envisioned for most microgrid projects. However, depending on the utility operating philosophy, strategic planning, and main project targets, there are others aspects that should be taken into account for the development of the microgrid operating procedures.

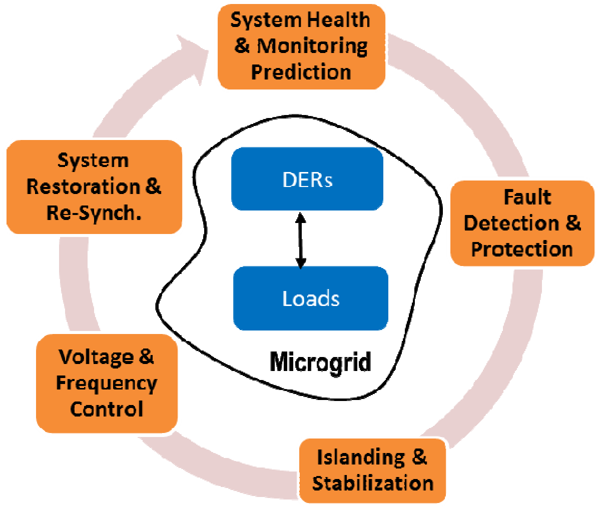

Figure 2: Microgrid operation stages

The following is a list of topics that must be studies for the development operating strategy of a microgrid system, as they can impact the project targets.

Table 1: Examples of operating strategies

Operating Strategy	Remark
Load management	Load shedding, customer categorization and service differentiation, generation curtailment or cycling, …
Generation dispatch grid supporting applications	Grid-connected operation
Islanding approach:	seamless, break-before-make, or hybrid
Islanded operation and power management	
DER control capabilities	V/f control, curtailment, …
Load sectionalizing and/or transfer	
Load restoration approach	
System reconfiguration	automatic or manual
Microgrid clustering	
Black start scheme	
Re-synchronization	passive versus active
System monitoring and supervisory control level	
Participation in energy market	

In the following paragraphs, some of the key operating strategies for a microgrid system and the approaches for their implementation will be described in more details.

Islanding

A microgrid should rapidly respond to external faults and/or power quality (PQ) issues, and get isolated from the main utility grid. This should be achieved through the coordination between the protective equipment located at the Point of Interconnection (POI) and upstream reclosers/breakers. Planned islanding can be done seamless when generation and load is matched between microgrid and utility grid. Unplanned islanding will normally require a short outage. In the unplanned case, customers will experience a short outage before the complete formation of the island. However, in this case, critical customers can remain energized if non-interruptible power supplies are deployed.

The use of direct transfer trip (DTT) scheme can significantly increase the effectiveness of the islanding process. The DTT can also improve the microgrid protection against internal fault, albeit at a higher cost. At the instant of islanding, three general scenarios can take place:

a) No DER is in-service: In this case, the entire microgrid will be shutdown (except critical loads, if supplied by non-interruptible sources such as battery energy storage systems). Depending on DER technologies, this case will cause a short interruption the length of which is dependent on system configuration.
b) Some DERs are in-service: In this case, if DERs do not ride through faults, a similar situation to Scenario (a) will take place. Otherwise, only a portion of microgrid loads should be de-energized by sending appropriate command signals to remotely-controlled switches (RCSs). Thus, the outage time of this scenario will be relatively shorter.
c) All DERs are in-service: In this case, if all DERs can ride through the PQ incident, the island can be formed seamlessly. This, however, depends on system condition prior to the incident and control and communication capability.

Resynchronization

Once the utility service has been fully restored, reconnection of the islanded microgrid to the utility grid requires synchronization to ensure voltages/frequencies in both sides of the POI breakers are within a specific range [2]. The microgrid re-synchronization can be achieved in two ways as follows:

a) Passive method: In this approach, the microgrid frequency setpoint is kept slightly below the main grid frequency. A synch relay is used to determine the proper point of voltage and phase angle matching and close in the circuit breaker.
b) Active method: In this method, microgrid controller continuously interacts with all the generation sources inside the microgrid to closely match the voltage, frequency and phase angle of the microgrid area with the main grid and close in the circuit breaker.

Circuit Reconfiguration

To enhance microgrid reliability, a reconfiguration approach can be employed to supply customer loads with different paths of possible power flow. Reconfiguration strategy would address faults within the microgrid and generation supply demand scenario. It is thus essential to consider this feature from the engineering and development phase. The feature is particularly attractive for the islanded mode of operation. Reconfiguration can be achieved automatically through real-time commands to RCSs within the microgrid. It is noted that communications between RCSs and microgrid controllers will be an essential part of the restoration process.

Load Restoration

Similarly, RCSs can be utilized to sectionalize the (cluster) microgrid in the islanded mode (as needed), and gradually energize the loads during the system restoration. The load management system can also help in the microgrid black-start operation.

Load categorization or load blocks should be utilized, in order to properly manage customer restoration and to meet customer expectations in terms of minimizing the interruption time and power quality level. An example of electric load categorization are shown in Figure 3.

- Critical customers within a microgrid include the most sensitive load and they are expected to always being served. A non-interruptible power supply and/or a short interruption as minimal as possible should be provided for these customers.
- Essential customers are the ones that should be quickly restored; however, short interruptions are considered acceptable.
- Adjustable loads (on/off type) and continuously controllable customer loads are becoming part of the demand side management schemes and load shedding. These loads are typically utilized to extend the microgrid islanding duration, based on the availability of generation resources. Parts of the customer loads in these categories will also need to be entered into fast load shedding schemes to manage frequency and voltage stability of the system.

For utility scale systems, load block creation and configuration is required to match generator load pickup capabilities with actual microgrid demand.

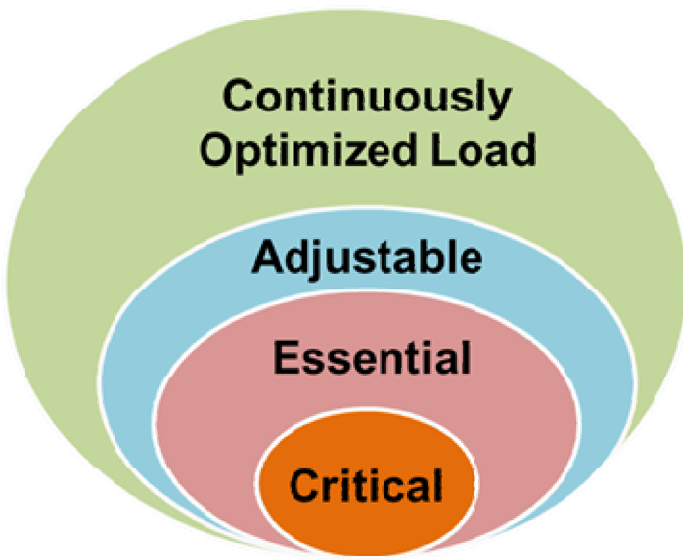

Figure 3: An example of load categorization for a microgrid

<u>Inverter Control</u>

Inverter-based DERs are often distributed within the microgrid footprint, which necessitates some level of controllability over inverters. While conventional DERs provide limited control functionalities, smart inverters offer several functions including fault ride-through beyond normal limits, dynamic Volt/VAR control, volt-watt control, soft-start reconnection, power factor control, emergency ramp rate, communication capabilities, etc. Such features can optimize microgrid operation in both islanded and grid-connected modes, and should be considered for a desire operating strategy [3].

Microgrid Control and Protection

This section outlines some of the control and protection features and advanced functionalities that would be part of the requirements for reliable and safe microgrid operations. Typical controller architectures and protection schemes commonly applied in medium and high voltage utility-scale microgrids are explained. The level of complexity in control and protection system design and selection may extensively vary by the type of the generation resources and microgrid functional requirements. Hence, this paper only reflects the general framework proposed for the control strategy and protection philosophy of utility microgrids with multiple customers and mix of both renewable and conventional generation units.

Control

One of the main motivations behind the rapid deployment of microgrids is the advanced control capabilities that they offer to local distribution companies. The principal roles of the microgrid control include voltage/frequency regulation in both operating modes, proper load sharing, islanding, resynchronization, power flow control between the microgrid and main grid, and microgrid operating cost optimization [4]. Since these control functionalities have different levels of criticalities, a hierarchical control structure has been widely accepted for control of microgrid systems. Microgrid hierarchical control strategy consists of three levels as follows:

- Primary/local control: This level of control is responsible for microgrid voltage/frequency stability subsequent to the islanding. This is the fastest control level (in the order of milliseconds, up to 1 sec), which is done by local controllers. Droop control is an example of primary control.
- Secondary/supervisory control: The voltage and frequency deviations caused by the primary controls is compensated at the secondary control level, by specifying steady-state voltage/frequency commands of DERs. In addition, the secondary control can shed loads in the islanded mode (depending on load criteria, microgrid energy reserves, or other constraints) or supervise resynchronization once the operating mode is to switch to the grid-connected mode. The time scale of this control level is in the order of seconds.
- Tertiary/management control: Management of power exchange between the microgrid and the utility grid and economically optimal operation of the microgrid (through determination of P/f or Q/V setpoints for DERs) are the main responsibilities of the tertiary control level. The time scale of this control level is in the order of minutes.

Hierarchical control strategy of a microgrid system is shown in Figure 4. While standard DERs offer limited primary controls, smart inverters are assumed to provide higher level of control capabilities including voltage/frequency ride-through, dynamic real and reactive power control, scheduling of outputs and functions, and communications with utilities and third parties. The existence of a platform based on the service-oriented structure is assumed for the integration of various functionalities. However, in some cases, the secondary and tertiary controls can be integrated into the distribution management system (DMS) platform.

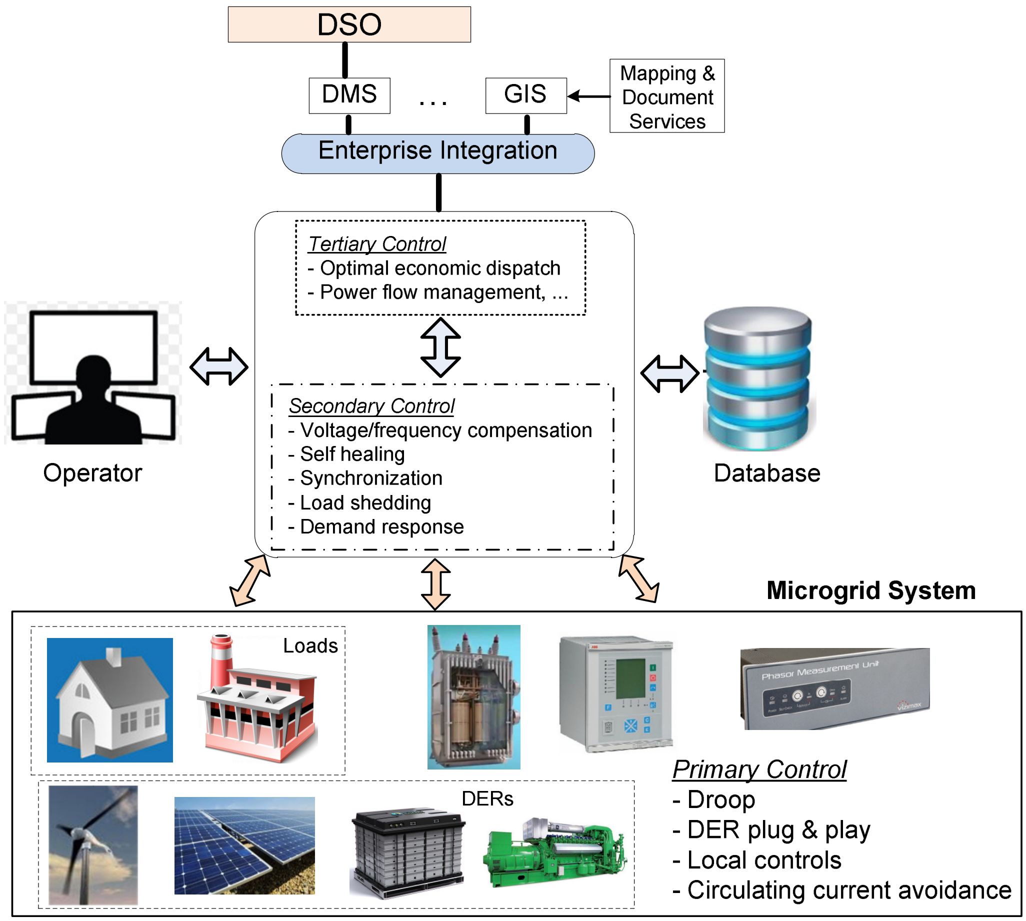

Figure 4: Hierarchical control levels of a microgrid

Protection

Operation of a distribution network as a microgrid introduces a new set of protection issues to utilities. Conventionally, overcurrent protective devices such as fuses, reclosers, and sectionalizers are utilized to protect distribution feeders. Considering radial structure of distribution networks, coordination of these devices is a straightforward task. However, varying configuration and operational mode of microgrids can potentially disrupt the coordination amongst the devices and challenge the distribution protection philosophy adopted by the utility.

In the grid-connected mode of operation, the utility grid normally contributes substantially to the fault current and, thus, the protection issues are mostly of the coordination type caused by DERs. However, in the islanded mode where the utility grid is absent, there is the reduced fault current which makes fault detection a very difficult task. Table 2 provides a summary of protection issues in a microgrid.

A number of solutions have been proposed in technical literature to address microgrid protection challenges in both operating modes [5]. In addition, an increasing number of jurisdictions are revisiting their regulations to ensure that DERs provide adequate fault currents, while preserving system reliability and/or stability. This is mainly to keep the required changed to the existing protection system at the minimum level. Nonetheless, design of an optimal protection scheme for a microgrid requires a separate study to be conducted on the microgrid system under development. Further, advanced protection strategies for microgrids require reliable communication systems [4], which could affect the economics of the project.

Table 2: A summary of microgrid protection issues

Operating Mode	Issue/Challenge	Contribution Factor
Grid-Connected Mode	Nuisance tripping	Increased fault current
	False/Sympathetic tripping	Multi-directional power flow
	Mis-coordination between overcurrent protective devices	Change in the fault current range of the feeders
	Blinding of protection	Unequal fault currents for OC protective devices in series
	Failed auto-reclosing and fuse-saving mechanisms	Presence of DERs
	Less efficient clearing of temporary faults	Presence of DERs
	Conflict between system protection and fault ride-through requirements defined in utility grid codes	Common with the islanded mode
	Impact of DER interconnect transformer on fault current	Winding configuration
	Differentiation between external and internal faults	DER contribution
Islanded mode	Mis-coordination between overcurrent devices	Bi-directional power flow
	De-sensitization of ground fault relays	Reduced fault current level
	Less efficient fault detection	Reduced fault current level

Technological Enablers for a Microgrid

Emerging advanced technologies play key rule in microgrid development in order to ensure safe and sound operation of a microgrid with the level of complexity expected. Various automation and monitoring technologies are utilized within a microgrid to achieve the level of observability, controllability and flexibility required for normal grid-connected operation and during system contingencies and grid outages.

Advanced Power Electronic Technologies:

Power electronic based distributed energy resources with advanced functionalities are commonly utilized in microgrids. The power electronic devices are either part of power generation and energy management systems, or they are incorporated for enhanced power quality and flexibility of the system. In general, they can be two grouped in two categories:

- Distributed Energy Resources: such as solar PhotoVoltaic systems (PV), microturbines, flywheels, and battery energy storage systems (BESS);
- Power conditioning units: such as distribution static reactive power compensation (D-STATCOM), and static switched or solid-state transformers (SST)

As the penetration of power electronic based generation sources in a microgrid increases, additional layers of control (dispatchability) and stabilization capabilities are required in these technologies. The advanced inverter requirements have been introduced in recent years to ensure the power electronic DERs can be remotely controlled to provide grid supporting functions. The main controls are:

- Power – frequency droop capability
- Dynamic voltage and reactive power compensation, through setpoint adjustment or voltage-reactive power droop characteristics
- Transient ride through capabilities; including low/high voltage ride through, frequency ride through and fault ride through features
- Remote control through communications
- Power dispatch (or power curtailment) and inertia emulation (in case of energy storage units)

Smart inverter functionalities in conjunction with resource forecasting features are part of the advanced microgrid control strategy that enable market participation to introduce additional revenue streams to the benefit of the business case, especially during normal grid operation.

Distribution Automation and Protection Technologies:

Microgrid operation relies on several distribution automation schemes and intelligent controls, such as

- Automatic fault detection, fault isolation and circuit reconfiguration (FDIR),
- Automated load transfer schemes,
- Integrated voltage and reactive power optimization schemes (VVO)

Automation functions are implemented through local controllers as part of intelligent electronic devices (IEDs) and coordinated through multiple dedicated site controllers (e.g. for each generation plants) or a centralized supervisory controller, such as a substation SCADA.

In addition, various levels of protections, remote monitoring and controls through system operator commands are needed to meet the grid integrity and stability criteria during sudden changes in the operating conditions and/or system contingencies. To consider some examples, similar to dispatchable generators, intermittent renewable resources should also be able to follow voltage reference set points issued by system operators, and curtail their output if there is more generation compared to the system demand from critical/base plants and/or low cost sources (e.g. hydro generators and nuclear plants).

Examples of typical control and protection functionalities implemented through field IEDs in a microgrid are listed in the table below.

Table 3 – Protection and control functions in field IEDs

Control Functions	Protection Functions
Alarms & Monitoring	Disturbance Records
Start-up & Shut down	Remote disconnect
Islanding	Transfer Trip
Power Dispatch	Forced Power Curtailment
Low/High Voltage Ride Through	Fault Ride Through
Power factor Set-points (e.g. 0.9 lead to 0.9 lag)	Under/Over Voltage Trip set-points
Dynamic Reactive Power (Droop) Control (e.g. 33% ΔQ for +/- 10% ΔV) for Voltage Stability	Under/Over Voltage Trip set-points
Frequency Regulation (e.g. using 3% or 4% droop)	Under/Over Freq. Trip set-points

Advanced Measurement, Monitoring and Communications Technologies:

Due to the real-time measurement and control requirements, and also because of the criticality of the some protection and operation schemes, high precision data capturing methods and more granular (high speed) metering devices need to be incorporated in the microgrid design.

The use of synchrophasor technology with phasor measurement units (PMUs) are recently been considered for distribution applications as the main source of the power flow and voltage monitoring for the microgrid operation as part of the load sectionalizing, restorations and microgrid stability monitoring. PMUs can be very effective in providing high-speed measurement for protection functions and feeding special measurements needed during re-synchronization and reconnection to the main grid. The data measurements from PMUs are all transferred in the same common data format using C37.118 standard. In addition, the data is time stamped to the same reference which makes it easy to aggregate and extract relevant information.

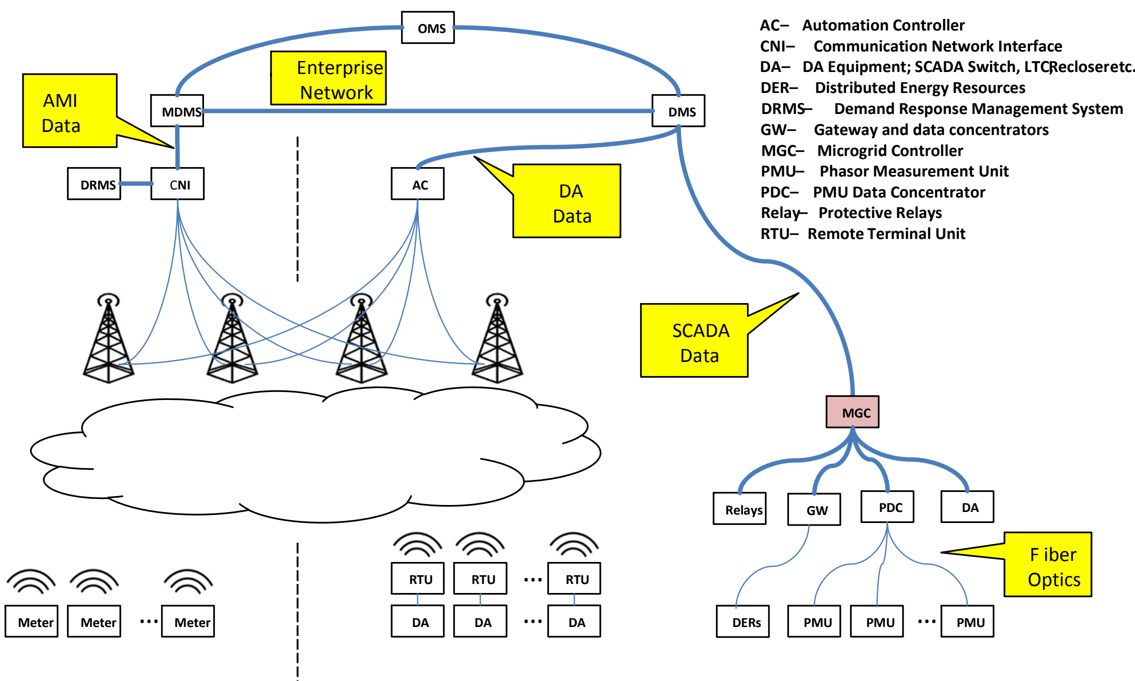

Figure 5: Integrating microgrids into typical communication system architecture for utilities

Figure 5 shows a typical utility system communications architecture in the context of integrating microgrids. In this integrated approach, microgrid is a critical component of the existing systems. Load measurement and feeder level data for the neighboring areas are provided to microgrids through existing SCADA and AMI systems.

There are a wide variety of communication solutions that can be considered for a microgrid, according to the target applications, and, more importantly, to the specific vision of what type and topologies a microgrid has. Economic factors along with technical limitation aspects are also among the reasons for electing particular technologies in detriment of others. The technologies targeted for the field area communication network can be classified and evaluated based on two aspects: a) public versus private networks, and b) wired or wireless technologies.

The communications services provided by telecommunication companies using their infrastructure, for instance based on copper, fiber optics, or cellular networks, is regarded by utilities with some skepticism. In these cases the contributing factor is the fact that they have limited control over the provided services, which may not guarantee the security, availability and reliability indices usually associated with the electric sector. For this reason, many utilities have been building their own private fiber and wireless networks.

Performance is also regarded as a matter of concern especially when critical real-time applications are considered. However, the use of these networks is considered acceptable, from the perspective of utilities, for noncritical applications in scenarios where due to technical or economic reasons it is not feasible to deploy private networks. Another scenario considered is the use of public operator based solutions as a backup or redundant communication service.

As an example, in case of a community microgrid, optical fiber is recommended to connect various points within the microgrid for protection and control purpose as it offers high reliability, high throughput, and low latency. The wireless technologies such as WiMAX can be used for the “last mile” communication to connect microgrid devices to contact point of LV network.

Utility Integration and Control of the Microgrid

Utilities are best positioned to leverage microgrid operations in a way that can provide benefits for the customers directly connected to the microgrid as well as those on the existing utility grid. Microgrids can provide utility grid customers with additional levels of reliability contingency and relieve circuit overloads on surrounding circuits. To enable these benefits, and to ensure safe and sound operation of the microgrids, utilities need to integrate control of microgrids with their existing distribution management systems (DMS). DMS integration ensures that the microgrids are utilized and properly operated as part of the day–to-day utility business, offering the most reliable and affordable solutions to the customers. As previously discussed, microgrids have a control hierarchy that performs critical functions (Figure 4). The primary and secondary control functions are focused on controlling local assets, load shedding, demand response, power quality, and synchronization. Tertiary control focuses on power/energy flow management as it relates to economic dispatch of generation and storage assets. While all three levels of control mentioned are critical for safe and efficient operation of the microgrid, they do not provide a level of control that interfaces the microgrid with the surrounding utility grid. It can be argued if this should be considered as the fourth level of control that manifests itself in the existing utility DMS system.

The existing utility DMS system is the platform that the distribution system operator (DSO) uses to monitor, control, and operate the existing utility grid. It provides a holistic operating interface for distribution system power flow and system configuration. Since utility connected microgrids are connected to the utility grid by design, they need to be included in the DMS system like any other conventional distribution system asset. Incorporation of microgrids in this system wide grid view will promote enhanced utility/microgrid interconnection configurations that will benefit customers on the larger utility grid. Potential benefits include additional levels of reliability contingency and load relief opportunities that will complement and enhance operation of the larger utility grid system.

The impact and benefit of the utility interconnection reinforces the need for the utility to manage the planning process for future microgrids. Utilities are best positioned to monitor utility grid profiles, capacity constraints, and future load growth. It can therefore be argued that microgrid location, size, and generation type needs to be part of the utility distribution capacity planning process to provide maximum benefit and prevent distribution congestion and undesirable power flows. In effect, a capacity planning process that is similar to what is currently in place on the transmission system may be needed. Installing microgrids in sub optimal locations will result in minimal benefit and create distribution power flow congestion that will negatively impact the larger customer base. As with transmission-connected generation, distribution generation needs to be located closest to the demand and in areas where the distribution system has the capacity to support the changes in power flow magnitude and direction at a minimal cost.

In addition to the reliability and load relief benefits mentioned, microgrids can provide economic benefit when the local microgrid generation and energy storage can be used to support system frequency needs or compete in the capacity market. This control function resides at the tertiary control level as previously reviewed; and is commonly referred to as the Distributed Energy Resource Management (DERMS) Platform. The DSO will operate the microgrid in parallel with the utility grid in economic dispatch mode when the microgrid is not needed for reliability or resiliency support. This operation allows the microgrid to provide economic advantage from the invested asset base when microgrid generation or storage is economically competitive with grid power or grid frequency regulation cost. For example, solar generation will operate continuously and supplement utility grid power as available, battery storage can operate to offset peak demand cost or compete in the wholesale market, and synchronous generation can operate when it is less costly than wholesale market prices. The DERMS controller allows the operator to configure and control how storage and distributed generation are deployed. If a storm is pending, a utility might decide to disable economic dispatch mode or might decide to proactively island the microgid to ensure microgrid customer reliability. The DERMS platform also provides the user with the ability to automatically constrain and configure how and when microgrid assets are dispatched in the marketplace. Regardless of the mode of operation, the utility DSO is best positioned to control the microgrid to attain maximum benefit.

Summary and Conclusions

This paper was intended to provide readers with an operational framework for the development of a utility integrated microgrid. The authors tried to touch on many of the challenges that will be encountered in the development of utility microgrids including site selection, technical design evaluation, operating and control strategies, protection, and integration with the existing utility grid. Each of these topics requires a deep dive and a significant investment in engineering studies to ensure the development of successful microgrid that provides maximum benefit. However, the overall considerations discussed in this paper can be beneficial to utility system planner/engineering, system integrators, as well as manufactures.

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