Considerations for Microgrids with Dissimilar Energy Sources

White paper by
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As more renewable energy sources and battery storage units are specified and incorporated into power systems, consultant specifying engineers are faced with many challenges which could impact the overall design and performance of these solutions. This paper outlines and addresses some of these challenges to aid in the system design, explains some common components found in microgrids, and discusses the value of an advanced microgrid controller for system operation.

The traditional top-down flow of electricity from large, centralized power plants, through transmission and distribution lines to a power meter has been experiencing disruptive forces over the past two decades due to de-regulation of energy markets, decarbonization, technology advances, availability, cost decline, higher customer expectations and increased penetration of renewable technologies.

Today, power consumers can become power producers as roof-top solar, behind-the-meter generators and battery energy storage systems become more economical and ubiquitous. Additionally, concerns about the reliability of the traditional utility electricity due to its aging infrastructure, extreme weather events and more sensitive loads have led to wider adoption of microgrids.

What is a microgrid?

A microgrid is a local energy grid with control capability. Microgrids can be disconnected from the traditional grid and operate autonomously. Some microgrids may be entirely off-grid and be the prime power source for the end-users it serves.

These microgrids may incorporate a variety of traditional and renewable power sources such as diesel or natural gas generator sets, wind turbines, solar panels, fuel cells, and energy storage. Microgrids may even incorporate combined heat and power (CHP) to address both electrical and thermal energy needs of its users. Through on-site generation with a microgrid, consumers of electricity can achieve their goals of increased resiliency, lower energy costs, greater independence, and reduced environmental impact by becoming producer- consumers or "prosumers" of energy.

Challenges when evaluating a microgrid application and incorporating dissimilar energy sources:

- Some of the considerations related to microgrid projects are as follows:
- Finding an optimal economic and environmental solution with the best Return on Investment (ROI)
- Identifying the right combination of traditional, renewable and storage assets to meet the operational and load demands
- Integrating the various generating, storage, controls and electrical distribution assets with simplicity
- Synchronizing and paralleling dissimilar energy sources
- Complying with grid code requirements for interconnection
- Ensuring 24/7 resiliency and uptime
- Handling changes in resource availability, such as cloud cover, changes in wind speed, and seasonal variation
- Ensuring both electrical and thermal loads aresatisfied consistently and securely
- Managing assets to ensure best efficiency and longest lifecycle
- Reducing utility demand charges
- Generating revenue through demand response programs, behind the meter applications and net metering
- Designing for future load expansion needs

Where to start?

When beginning to evaluate a microgrid project it is important to:

- Identify the goals of the project and customer in undertaking a microgrid project
- Engage the local utility to understand interconnection requirements in the case of a utility connected and evaluate if the cost and complexity of interconnection can be avoided through a system architecture such as "open transition" to and from utility
- Conduct a feasibility study and stability analysis

A feasibility study will evaluate the needs and constraints of the specific site and customer to identify a wide range of design options. The feasibility study will look at assets such as synchronous generator sets, battery energy storage, solar, wind and fuel cells, etc. to find the best mix and sizing of each asset to achieve the project goals. Through this energy model, a representative system can be evaluated for the key metrics of the system such as levelized cost of energy (LCOE), system emissions, renewable penetration, energy shortfalls, fuel consumption, etc.

The energy modeling begins with a detailed analysis of the site's load profile at 15-minute to 1-hour intervals for an entire year and a review of the exact site details to determine the wind availability, solar radiation, etc. for the specific geographical location being considered.

Finally, by investigating existing utility charges and/or on-site fuel consumption, a variety of solutions can be measured against the baseline or status quo.

Various assets can be considered in the energy model and the sizing of these assets can be constrained based on site-specific information. For example, while solar panels are cost competitive both from an initial investment and operating expense perspective, they take up a significant amount of space. Another common constraint is the availability of specific fuels for generator sets at the project location. The energy model will determine how each of the chosen assets should be utilized to reduce the LCOE and maintain power to the microgrid. For example, the energy model will find the best time to utilize grid power, when and how to charge batteries, and when to utilize generator sets in the system.

A system stability analysis will ensure adequate power quality (i.e., frequency, voltage deviation, etc.) and eliminate system disturbances. The stability analysis will confirm that the various energy assets being considered for the microgrid will maintain the required electrical quality to maintain continued operation and prevent damage to connected loads. Through these two analysis steps, the most efficient and stable integration of assets can be optimized for the specific drivers of the project such as the lowest net present cost or lowest system emissions.

Components commonly found in microgrids

INVERTER BASED TECHNOLOGIES

Photovoltaic panel: Photovoltaic, or solar, panels are made of silicon cells which when exposed to sunlight change their electrical characteristics and generate electric current. PV Panels are typically mounted on the rooftop of buildings, above parking garages, over carports, or in open space at ground level. They require a large amount of physical space unobstructed by shade.

PV panels are a Direct Current (DC) power source and require an inverter to transform the DC power to Alternating Current (AC) for use in most common electrical devices.

Solar panel costs have recently fallen drastically, and they have an extremely low or even non-existent marginal cost of generation making them a valuable asset in a microgrid. They are, however, a highly intermittent power source — only producing energy when solar radiation is available during the daytime. PV panels alone cannot provide uninterrupted electrical reliability and are increasingly being paired with battery energy storage systems to ensure greater utilization and reliability.

Battery energy storage: Battery storage is another common component found in microgrids as, when coupled with intermittent energy sources like PV panels, can address the curtailment and irregularity of renewable energy sources. During the day when solar energy is abundant energy produced in excess of the load demand can be stored in batteries to be discharged overnight rather than being curtailed. Batteries can also be charged by utility power, if allowed by the utility, when utility rates are lowest and discharged during high-rate periods or to avoid costly demand charges.

Lithium-Ion batteries are currently the most prevalent technology used in stationary storage applications due their high-power density, low costs, and durability. Energy storage systems can be utilized in both off-grid and grid connected systems and can be used to supply near instantaneous power during grid outages or during dispatchable asset start up events. Battery storage can also be used to improve the transient response during large load changes. As with PV panels, batteries are a DC power source and utilize inverters to charge or discharge to an AC electrical system.

Other technologies used in microgrids: Microgrids can also utilize other power technologies such as wind turbines and fuel cells. Wind turbines, like PV panels, are intermittent sources which produce power when there is adequate wind. Geographic location has a major impact on the viability of using wind energy in a microgrid but in the right location can be very beneficial.

Fuel cell technology has been steadily improving with higher efficiencies, increased power density, and reduced costs leading to more microgrid projects considering fuel cells. There are different fuel cell technologies available such as Proton Exchange Membrane (PEM) fuel cells and Solid Oxide Fuel Cells (SOFC) which can accept and generate power from different fuel sources PEM fuel cells utilize very pure hydrogen (H2) to produce power while SOFC can utilize a variety of hydrocarbon-based fuels such as biogas, natural gas, propane, and hydrogen. When considering a fuel cell for a microgrid it is important to understand the performance characteristics of the chosen fuel cell as well as have a good understanding of the supply chain and costs of the required fuel.

Inverters: To connect the DC output of solar, storage and fuel cells to an AC network, the DC output must be inverted to AC power first. Inverters, which are semiconductor-based electronics utilize Insulated- Gate Bipolar Transistors (IGBTs), are used to invert the DC power to AC power. In addition to inverters, filters and other electronic devices are used at different stages of the conversion to produce a clean sinusoidal waveform. Figure-1 shows the typical inverter stages. The AC output is achieved by turning on/off the IGBTs at a pre-defined sequence and speed which generates pulses of currents which is known as modulation, Figure-2. There are multiple modulation techniques such as Pulse-Width (PWM), Pulse-Frequency, and Pulse- Amplitude. PWM inverters are the most common as they eliminate lower order harmonics and decrease the Total Harmonic Distortion (THD) content in the output AC voltage.

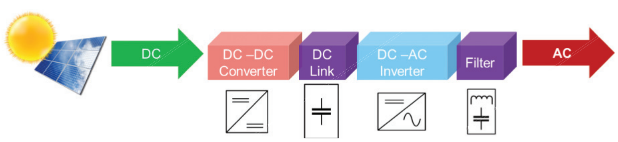

Figure 1. Typical inverter stages

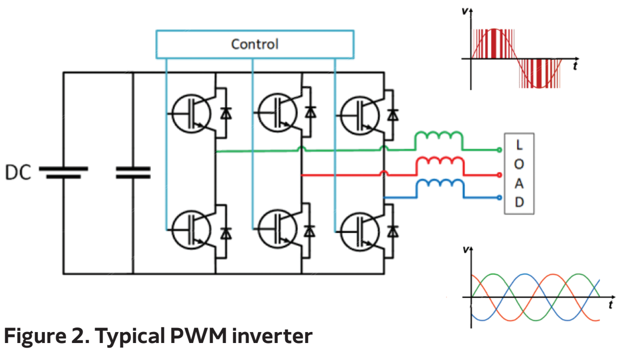

Figure 2. Typical PWM inverter

Inverters can be grid forming or grid following. In grid following, a voltage reference must be established by another AC energy source such as the utility or a generator set before the inverter is able to synchronize and connect to the network. In grid forming inverters, the inverter does not require a reference voltage and can establish the voltage of the network independently. Solar inverters are most commonly grid-following, whereas storage inverters can be either grid forming, grid following or both.

SYNCHRONOUS MACHINES

Generator sets: While PV panels and batteries are DC power devices, most electrical equipment utilizes AC power. A generator set, by its nature, generates AC power and can directly be used to power AC loads on demand and can be paralleled with other AC power sources such as the utility grid.

Incorporating a synchronous machine into a microgrid application has many benefits. A generator set is a dependable, dispatchable energy source which, if fuel is available can be utilized to meet the electrical load demand. Generators, with their high- power density, can start quickly, accept large block loads, and provide a reference to grid following components such as PV or battery inverters.

With intelligent controls in modern generator sets, autonomous synchronization and load sharing can be done at the equipment level and there are a wide variety of generator sets available at various power levels that accept different fuel types. Generator sets provide inertia to a system that inverter-based generation cannot provide, contributing to the overall stability of the system. Some microgrids, consisting of synchronous generators and PV energy for example, will require a minimum capacity of synchronous generators to be operating at all times to maintain inertia.

Generator sets selection should consider the fuel available at the project location, the expected usage, emissions requirements, noise limitations, and the microgrid's configuration. There are many different generator set technologies available on the market that can meet the needs to microgrids.

The two most common concerns when utilizing generator sets for microgrids and prime applications are noise and emissions with increasing pressure to be environmentally and socially responsible. Modern generator sets are available which exceptionally low emissions due to advancements in combustion and after-treatments technologies. Additionally, low carbon fuels such as Renewable Natural Gas (RNG) and biogas can be used for carbon neutral operation. Noise can be addressed through highly sound attenuated enclosures and buildings. Noise and emissions at the site level can also be minimized through intelligent controls which optimize the use of each asset to minimize the duration and timing of operation.

Paralleling AC power

To parallel or connect alternating power sources, several characteristics of the AC output voltage must be the same or within an acceptable range. It is essential that the waveform and phase sequence are the same. Also the frequency, phase angle and voltage amplitude must be within the acceptable range to safely and effectively parallel the AC sources, Figure-3.

Synchronous generator sets naturally produce AC voltage and they can be either in load sharing (analogous to grid forming) or in load govern mode (analogous to grid following) which are the terms used to describe the generator set paralleling functions. Load sharing is the proportional division of kW and kVAR total load among multiple generator sets in a paralleled system. Load sharing is essential to avoid overloading and stability problems on the paralleled generator sets. In load sharing the generator sets regulate their voltage and frequency. Load sharing can either be isochronous (where voltage and frequency stay constant at a 100% regardless of the load) or droop (where the voltage and frequency vary as the load varies).

The advantage of isochronous load sharing is the constant voltage and frequency; however, it requires the sources to communicate with each other. On the other hand, droop does not require communication interconnection between the power sources at the expense of varying voltage and frequency as the load varies.

The load govern function applies when a generator set, or multiple sets are paralleled to a utility or the grid. Because the utility voltage and frequency are fixed, the generator sets regulate their kW and kVAR output, instead of their frequency and voltage.

It is expected that the synchronous generator onboard paralleling controls to have paralleling and protection capabilities built in. The generator sets' paralleling control is typically responsible for all the following:

- Paralleling functions
- First start arbitration
- Synchronizing (Ø, V, Hz)
- Load sharing (kW and kVAR) Protection
- Metering
- Alarms
- Built-in safe manual paralleling

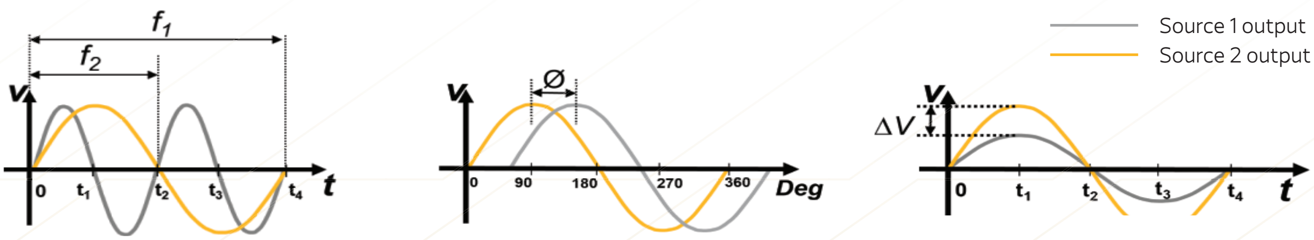

Figure 3. Synchronizing frequency, phase and voltage sources

When it comes to renewable energy sources and battery storage units, the output voltage is DC and therefore an inverter will be utilized to invert the DC into AC, Figure-4. Typically, photovoltaic inverters are grid following whereas storage inverters can be both grid forming and/or grid following.

Inverters are responsible for the lower-level synchronization, protection, and metering. However, one essential aspect when paralleling is load sharing across all the sources.

Load sharing across synchronous generators is simply accomplished via the on-board paralleling control and it can either be isochronous, the most common and preferred method or droop as described earlier. When it comes to load sharing with inverters, one method would be to set the generator sets to operate as the utility (load sharing/grid forming) and the inverters would operate in grid following and act like a constant real-reactive power (PQ) source. And an external control system would send these PQ commands to the inverter.

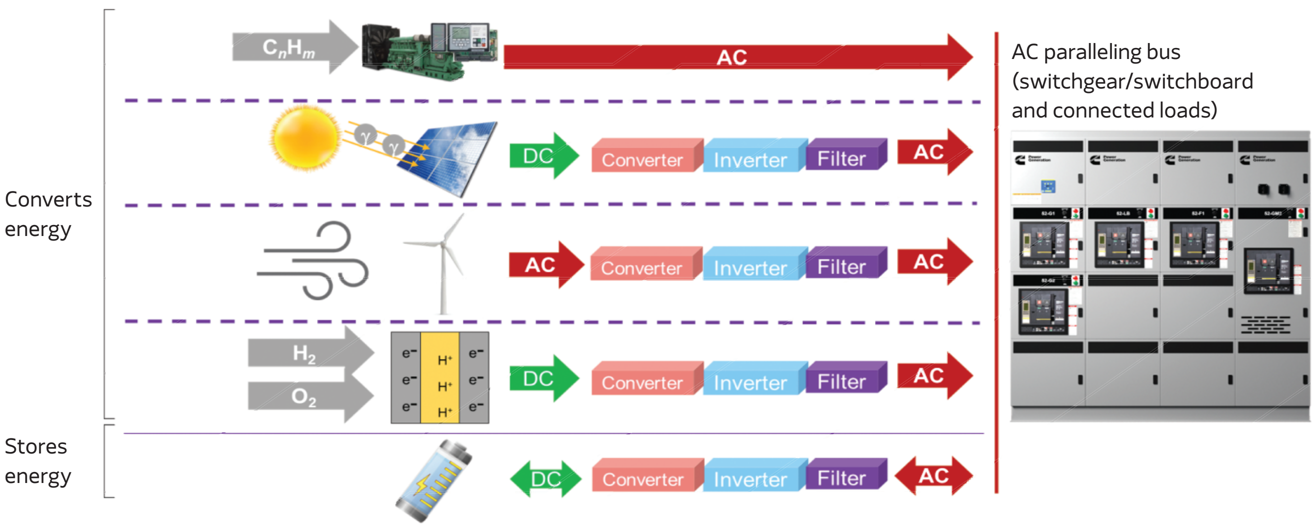

Figure 4. Dissimilar power sources

Microgrid controller

At the heart of any microgrid power system there must be an autonomous controller (Figure-5). The microgrid controller is expected to do, as a minimum, the following:

- Optimize energy production from all energy sources to meet demand
- Maximize the output power of renewable sources
- Control loads via load add and load shed
- Minimize emissions and fuel consumption
- Achieve the lowest Levelized Cost of Energy (LCOE) and Total Cost of Ownership (TCO) for all assets
- Allow for monetizing assets via grid support and demand response programs
- Ensure assets in the system are best utilized
- Adapt to changing weather conditions (i.e., cloud cover, wind speed and other conditions)
- Operate the system entirely or partially off-grid
- Monitor and/or control assets remotely with real- time notifications

What is not expected from the microgrid controller is the lower-level machine-to-machine operations such as synchronizing, load sharing and protection. By moving these operations to the individual machines, single point of failure is eliminated and therefore reliability is increased. Failure of the microgrid's autonomous controller does not jeopardize the reliability of the microgrid power system. Any failures must be analyzed and mitigated for safe and reliable operations which is typically performed by the microgrid controller provider.

Value of single supplier / integrator

Microgrids, which incorporate a wide variety of assets such as PV panels, energy storage batteries, utility power and generator sets, can seem intimidating with all the complexities of integrating these energy sources. It is critical to work with a reputable system designer and supplier who can not only provide engineering guidance on the size, mix and configuration of the optimum assets for a project, but can also deliver the individual components, integrating them into a solution all the way through to commissioning. While every effort is taken to engineer out issues, with the complexities of microgrid projects, challenges are often unavoidable. Having a single integrator on the hook to resolve issues is invaluable. When a system is delivered by a single integrator there is no risk of finger pointing between component suppliers and the project will ultimately be more successful.

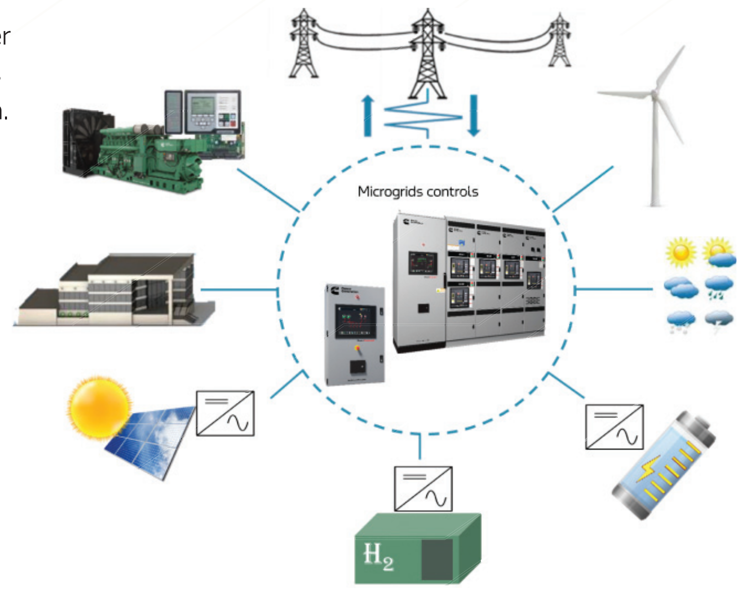

Figure 5. Microgrid Controller

Summary

Microgrids can provide significant benefits for **resiliency, sustainability and cost savings**. Every project should begin with a feasibility study and stability analysis to determine the best mix and sizing of assets to meet the goals of the project. The sequence of operation should be written to ensure system resiliency and power quality with mitigated failure modes. The integrated paralleling and protection controls for the synchronous generator sets as well as the microgrid controller are critical components to ensure seamless operation, system recovery, failure mode analysis and system optimization. As with all specifications, the microgrid specification should be based on function and performance. Working with a reputable power system supplier who fully understands the power system design space can ensure a well-engineered solution which will achieve the project objectives.

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Bulletin 6408992 Produced in U.S.A. Rev. 9/24