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Challenges and Considerations of DER Selection for Microgrid Applications

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SUMMARY

Adoption of Distributed Energy Resources (DERs) in microgrid applications can improve system reliability and power quality while reducing the cost of electricity through on-site generation. When selecting DERs for microgrid applications, several factors need to be considered. This paper will explore many technical considerations and challenges of DER selection based on real-world microgrid experience. Some of these challenges include the power and energy delivery capabilities of resources, steady-state performance, response to load variations, behavior during system faults, paralleling limitations, and power system grounding. In summary, this paper will enumerate challenges that must be considered when selecting DERs for integration in microgrid systems.

KEYWORDS

Microgrid, Distributed Energy Resources, Droop Control, Harmonics

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1 Introduction

In microgrid systems, a portion of the power system can run interconnected with the bulk power system (the larger grid), or independently in an islanded state. These microgrid systems include Distributed Energy Resources (DERs) and local loads, with clear electrical boundaries. When selecting DERs for use in microgrid applications, many challenges arise, and many considerations are needed. This paper enumerates several challenges and considerations for microgrid DER applications, from a power system perspective, that the authors have encountered in the real-life microgrid projects. These challenges include active power and energy considerations, DER response to system events, and paralleling and interconnection challenges. There are also financial considerations when selecting DERs for microgrid applications, which are out of the scope of this paper.

2 Active Power and Energy Considerations

When selecting DERs for application in microgrids, it is important to consider the steady-state active power each resource can produce to supply the system loads. Additionally, the amount of energy available is significant to evaluate the duration that the islanded system can operate. Both power and energy constraints will be discussed for generators, battery energy storage systems (BESS), and renewable resources.

2.1 Generator Active Power and Energy Considerations

Generator active power output is constrained by the engine. The engine limits steady-state operation at both the lower and upper end. For a given generator and engine, there is a maximum rated output of the engine itself. While the engine is typically capable of producing the rated power for some duration, the engine also has a parameter called the load factor [1]. The load factor specifies that on average, the engine should run at less than the specified percentage of the rated load. At low power outputs, generators typically run less efficiently, as some power required to keep the mass rotating at rated speed. Many generators will have a minimum continuous power output. For example, diesel generators, if operated at low power output, can experience "wet stacking" [2]. In this scenario, the fuel is not completely combusted, and is deposited within the engine or exhaust system.

Generator total energy output during islanded operation depends on the type of fuel, and how it is stored. In many cases, such as when using diesel fuel, the generator will have a fuel tank, and the capacity of that tank will limit the total energy output during islanded operation, unless the fuel tank can be refilled during the islanded operation. In other cases, such as when using natural gas, it may be possible to supply the generator from utility natural gas service.

2.2 BESS Active Power and Energy Considerations

A BESS typically has clearly defined active power and energy ratings. One important consideration is the significance of the energy rating. Depending on battery chemistry, manufacturer, and specifications, usable energy may significantly vary. For example, the minimum and maximum state of charge will vary, which will limit the total energy input and output. Additionally, battery charge and discharge cycles have an impact on the energy capacity of the battery over its lifetime. The impact of the charge and discharge cycles will vary with chemistry and manufacturer.

2.3 Renewable Generation Active Power and Energy Considerations

Renewable generation active power output is constrained by the availability of the power source (e.g. light for PV panels, or wind for wind turbines), and the capability of inverter. Renewable resources, unlike generators or BESS, are not dispatchable. Typically, the renewable resources are treated like negative loads – the power they output is utilized when available. Renewable generation can be curtailed, if their power or energy output is excessive (e.g. if renewable output exceeds load, and the battery does not have additional capacity to charge). These resources can be coupled with energy storage to supply energy to loads for extended durations.

3 DER Response to System Events

Another significant consideration for selection of DERs for microgrid applications is the response of the DER to system events. Two events that can be particularly impactful to the operation of microgrid DERs are faults and mismatches between load and generation. These events are handled differently by rotating machine generators and power-electronic interfaced generation.

3.1 DER Response to Faults

Faults within an external to the microgrid system can be significant events, and cause differing responses from various DERs. It is important to understand DER behavior during fault events to ensure system protection is designed to detect and isolate faults quickly. During islanded operation, faults must be cleared promptly to protect the system and equipment, preserve system stability, and to avoid disrupting the power quality at microgrid loads. While interconnected with the bulk power system, microgrid DERs must be isolated from the system fault, but also retain availability in case islanding is subsequently desired.

3.2 DER Response to Load and Generation Mismatches

When operating in an islanded microgrid, mismatches between load and generation may also be significant events. Load and generation mismatches can be caused by scenarios including black-starting the microgrid, significant load changes, or loss of generation. These events are particularly impactful to the system while islanded because the system is less stiff than the bulk electric power system (i.e. microgrid systems have relatively low short-circuit ratio and inertia), and thus experiences more significant variations in frequency and voltage when there is an imbalance in load and generation. The frequency and voltage variations during normal islanded operation should be studied in the context of the sensitivity of system loads to ensure that appropriate system stability and power quality is maintained throughout operation.

3.3 Generator Response to System Events

Generator fault current output varies as a function of time. The initial response of the machine decays as a function of the alternator electrical parameters (e.g. subtransient and transient impedances). The fault current after the initial several cycles is driven by the generator automatic voltage regulator (AVR) and excitation system, which can adjust field current to change fault current output. Furthermore, fault current can be impacted by the phases involved in a fault (e.g. single-phase-to-ground or three-phase faults) as well as the machine temperature. [3]

When active power demand does not match generation, the system frequency changes. This occurs because the difference between the load and generator causes the machine mass to accelerate (if generation exceeds load), or decelerate (if load exceeds generation). System inertia defines how fast the frequency changes during these events, with lower inertia resulting in faster changes in frequency. AVR controls will commonly adjust voltage when the frequency deviates to help the machine recover. An example plot displaying system frequency of a simulated system after a generator has tripped offline at 1 second is shown below in Figure 1. In this example, the generator tripping caused a generation deficit and subsequently the system frequency drop. In such situations, some corrective actions, such as load shedding or re-dispatching other generators, need to be taken to recover the frequency of the system back to its normal level.

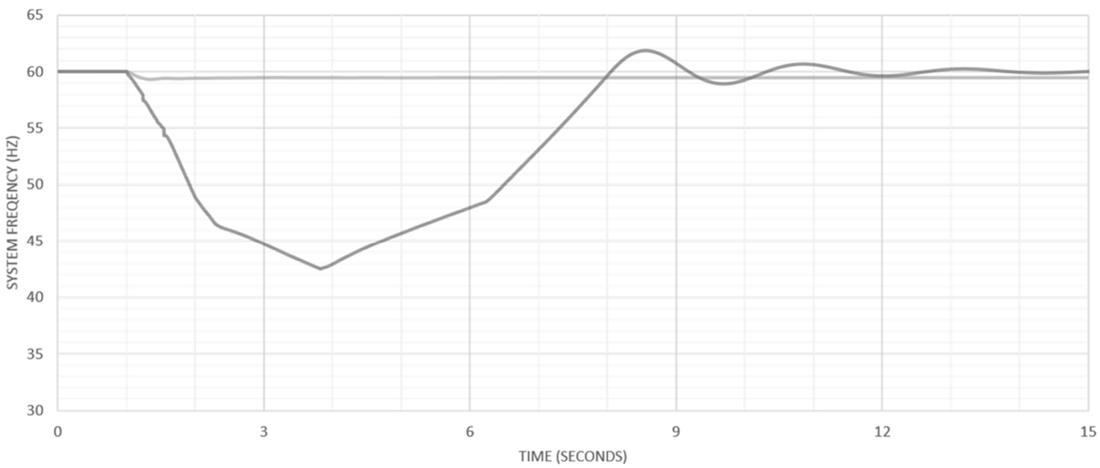

Figure 1: System Frequency After Generator Trip

Generator protection commonly includes overvoltage, undervoltage, under-frequency, over-frequency, and overcurrent elements. These protection elements require careful consideration to ensure that the machine is protected and faults in the microgrid are detected. Protection should also consider whether the generator should trip during load and generation mismatches or system faults while interconnected to the bulk power system.

3.4 Inverter-Interconnected Resource Response to System Events

BESS and renewable resources are commonly connected to the power system through power electronic conversion systems. These inverters have tripping and ride-through characteristics that are significant to microgrid operation. As described above, during system events, the system frequency and voltage may significantly deviate from nominal. If the inverter cannot ride-through and continue producing power during these events, it can challenge system recovery. For example, during a black-start scenario, if generation resources trip offline because of low frequency and voltage during energization, it will reduce the amount of generation available to supply the newly connected load, exacerbate the low frequency and voltage conditions. Similarly, during a fault condition, if the inverter-interconnected resources cannot ride through the event, a fault that can be quickly detected and cleared may leave the system unable to recover because of inadequate generation.

Inverters typically supply very limited fault current, e.g. around 1-2 per-unit of rated current output. In many cases, inverters will simply trip offline during system events. This limited fault current and sensitive tripping behavior can challenge fault detection and isolation.

3.5 *Speed of Response to System Events*

The speed of response of different DERs to system events also varies. This speed is a factor when the event occurs, or when calling on a resource to respond to an event.

Generator speed of response is driven by factors including the size and engine. As described above, when an event occurs, the machine and system inertia is a factor in the rate off change of frequency in the system. The physical mass of the machine impacts its inertia. In general, physically larger machines have more inertia. The speed that the engine can ramp power output up or down also impacts the device response, as an event on the system will require output power changes. The power output ramp behavior will impact how the machine and system can recover from an event. Additionally, generators may be called upon to start during a system event. Depending on the type of generator, starting the machine can take seconds or minutes.

Inverter-interconnected resources speed of response is driven by factors including the availability of the resource, its capability to ramp, and inverter capabilities. First, the availability of the resource (e.g. solar PV power or battery energy storage) and the output at the time of the event impacts whether the resource can respond by ramping power output up or down as required by the system during the event. The inverter's ability to execute a controlled power output change during the event also dictates if the resource will be able to respond to the event, and if so, how quickly. Inverter-interconnected resources, if their power output is available and quickly able to ramp output, can change power output or start within seconds or faster during events.

4 Paralleling and Interconnection Challenges

When selecting DERs for microgrid applications, interoperability of resources with each other and the bulk power system must be considered. Some significant considerations that impact DER interoperability are load sharing, harmonics, synchronization, and system grounding.

4.1 *Load Sharing*

The microgrid load is shared by the combination of DERs installed in the microgrid. Some sources will be set up to function as a reference, like a slack bus in the bulk power system, and produce or consume power as required by the system. There are several ways in which local generation controls can be configured to share power between resources. Operating resources with isochronous controls will cause them to vary active and reactive power output to attempt to maintain a constant voltage and frequency at their output. When operating multiple resources with isochronous controls, a fast-acting overarching controller controls each resource to balance power output and avoid instability. Isochronous load-sharing controllers are commonly available when paralleling physically close generators from the same manufacturer. However, paralleling DER from different manufacturers at locations that are not physically close can be addressed with different mechanisms. One common local control scheme is droop. In droop operation, a DER operates at lower frequency at higher active power output, and higher frequency at lower active power output. Reactive power can similarly droop as a function of terminal voltage magnitude. Droop enables parallel resources to share active and reactive power output without fast acting controls communicating to each resource [4]. Note that droop settings must be appropriately tuned to ensure stable operation. A slow acting overarching controller can adjust the power sharing of droop-controlled resources by adjusting their no-load frequency and voltage settings or adjusting droop slopes.

4.2 DER Harmonics

Harmonics are another attribute that requires consideration when paralleling DERs in a microgrid. Each resource discussed in this paper has associated harmonic content. Generators have varied harmonic output based on the pitch of their alternator windings. Paralleling generators with alternators of varied pitch may require harmonic mitigation [5]. Power-electronic interfaced resources also have harmonic output, as their power conversion systems involve high-frequency switching. DER harmonic current and voltage levels should be studied to ensure harmonic levels meet industry standard requirements, and that DERs are capable of interoperability.

4.3 DER Synchronization

Another aspect of DER that needs to be considered is the requirement for synchronization. When each new DER connects to the microgrid system, it must synchronize with the other resources on the system. This necessitates synchronization and synch-check relaying at points of interconnection between resources and between the microgrid and the bulk power system. Additionally, the requirement to synchronize may limit the ability to repurpose old generators and interconnect them to the microgrid.

4.4 System Grounding

Grounding of the power system must also be considered in microgrids that are capable of operating islanded, and disconnected from the bulk power system. In many power systems, particularly in North America, the power system is operated effectively grounded. In these systems, it may be desirable to continue operating as an effectively grounded system while operating islanded.

A simple option to maintain grounded operation while islanded is to interconnect resources such that a zero-sequence current path is always provided. However, operating with a normally connected zero-sequence current path means that zero-sequence unbalance during normal operation will be partially supplied by the DER, and ground faults will cause zero-sequence current to flow through the DER. This may have impacts on local ground fault protection, which should be considered.

Another option to maintain an effectively grounded system while islanded is to have a switched zero-sequence current path (e.g. a grounding transformer or fast grounding switch). The switched zero-sequence current path could be closed to allow effectively grounded operation while islanded. The zero-sequence current path could be switched out while operating in parallel with the bulk electric power system, avoiding contribution to ground faults or sharing unbalanced load with the system.

5 Conclusion

When selecting DERs for utilization in a microgrid, many aspects of the resources must be considered. For each resource, the active power and energy associated must be considered to ensure load can be supplied while islanded, and to assess the duration that the microgrid can operate islanded. The response of DERs to system events, including faults or load and generation mismatches, should be carefully assessed to ensure it enables system recovery, including fault detection and isolation. Finally, interconnection of DERs should consider load sharing, harmonics, synchronization, and grounding to ensure that resources will interoperate as intended.

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