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microgrid control systems

a practical framework

A GROWING INTEREST IN MICROgrids has brought a great level of focus, creativity, and investment in the development and commercialization of microgrid control systems (more commonly called controllers). The primary value propositions for microgrids are improving reliability and resiliency, enabling renewable generation integration at a higher penetration level than normal, enhancing efficiency, and the economic dispatch of distributed generation to reduce operation and maintenance costs and create new revenue streams (for instance, through participation in the energy or ancillary service markets). All of these efforts emphasize the need for a microgrid control system that can operate the system autonomously in a coordinated fashion to achieve predefined performance goals.

Technologies applied in a microgrid (both as individual assets and as part of the overall scheme) and operating procedures play important roles in determining microgrid performance, particularly with the proliferation of distributed energy resources (DERs) and the utilization of emerging power electronic technologies, which introduce complex behavior. Therefore, a prominent question discussed in the industry is what requirements does a controller need to satisfy to meet the microgrid operation objectives and accompanying performance metrics and at what cost?

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Effect of Operating Strategies on Microgrid Controls

Figure 1 shows a framework for microgrid control system development, comprising multiple contributing elements: technology characterization to determine asset-level control capabilities; the development of operating strategies and functional requirements for the system; the determination of available or required monitoring, protection, and communication schemes; and the identification of comprehensive testing and performance verification approaches. To select a proper microgrid control system, the contributing elements need to be carefully analyzed to determine appropriate approaches and alternative solutions from a variety of applicable schemes and realization methods. Possible choices and design variations for microgrid operating strategies and associated functional requirements are as follows:

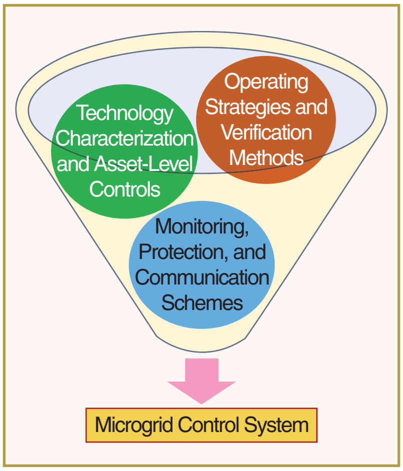

figure 1. The framework for microgrid control system development.

- ✔ The preference between distributed versus centralized control systems for secondary (supervisory) controller(s):
  - primary (or fast) controls are by nature distributed due to being dependent on the types of the assets and their control functions
  - the supervisory controls in charge of coordinating the operation of the microgrid components to achieve certain performances can be centralized in one location or physically distributed across the topology of the system
- ✔ A selection of microgrid load-serving capacity (generation to load ratio) and the level of the autonomy (islanding duration), which defines whether a microgrid can serve its entire load at all times or would require some methods of load management (load categorization, followed by load shedding and restoration).
- ✔ The determination of microgrid islanding and isolation strategies either as a seamless transition for all loads or possibly a break-before-make approach. This requirement is dependent on whether all customers or some customers can tolerate a momentary outage (not longer than a couple of minutes) prior to service restoration.

(continued on p. 110)

Customer tolerance for outages determines the complexity of the control system design and technology requirements at the point of interconnection.

- ✔ Black-start capability and load restoration procedures. Black start may be performed by a dedicated generator, or a microgrid can be further divided into smaller regions (nested islands) to maintain the high level of reliability for selected customers while restoring the rest of the system.
- ✔ The method of voltage and frequency controls (e.g., droop schemes versus isochronous or master-slave controls).
- ✔ Power sharing and load following methods for frequency restoration and determination of the reserve capacity levels (or sizing of dispatchable units versus nondispatchable generators).
- ✔ The determination of the type of contingencies that a microgrid should act upon (e.g., power quality related and/or faults), detecting and differentiating an internal versus an external event, and the acceptable response time, such as any ride-through requirements imposed by the area electric power system owner prior to disconnection or the duration and steps involving the fault clearing process;
  - microgrid controls may need to respond to N-2-type contingencies such as the sudden loss of a key generation unit or inception of an internal fault, during the period of island operation by aiming to restore some customers through fault clearing, sectionalizing, and service restoration
  - microgrids may fully go through a shut-down process after an internal fault or loss of a large generation unit.
- ✔ The evaluation of protection issues associated with low short circuit capacity and adapting to different conditions during islanded and grid-connected operating modes. Technologies, such as communication-assisted protection schemes, negative sequence protection methods, and synchronized phasor measurements, provide possible solutions but there are not necessarily off-the-shelf products that can fully satisfy the requirements.

Once the control requirements are fully understood and documented, the next step is to identify a commercial platform to meet the control requirements and operation objectives.

State of Commercial Microgrid Controllers

At present, most vendors offer a microgrid control solution, rather than a set of microgrid control products that can be obtained off the shelf and be applied to a project by the system owner's engineers. Furthermore, similar to many new emerging technologies, many available solutions are utilizing proprietary platforms either for controls or communications. Applying controls as a solution requires extensive detailed design and engineering performed solely by the vendors, which adds to the project's cost and duration and, arguably, also makes it difficult to maintain. In addition, the proprietary aspect of the control system can create challenges regarding the sustainability and maintainability of the approach in the long run since the microgrid system characteristics can change due to technological changes in generation units or just by adding a new component or load to the system.

> System owners should have some level of flexibility and accessibility in implementing the controls.

Although proprietary approaches may be justified because a higher level of security and reliability can be achieved, from the maintainability perspective, the approach could introduce business challenges and associated high service costs. In general, system owners should have some level of flexibility and accessibility in implementing the controls. For instance, an owner may decide to add a new photovoltaic system to the microgrid or incorporate additional customer buildings (as new loads) after commissioning the project. The associated modifications at this level should be carried out by the utility or owner's engineers, with minimum vendor involvement.

This argument is one of the reasons supporting the need for standardizing the core microgrid control functions and defining common development and validation procedures for microgrid control systems. In addition, defining microgrid controls should incorporate several other aspects, including available measurement and monitoring devices, interrelationship between protection functions and controls, and the ability of a system owner or operator to remotely access the microgrid assets (either through a supervisory control and data acquisition system or energy/distribution management systems) for manual operation and to override certain actions. Although the aim of microgrid controls is to function autonomously, there should not be conflicting actions due to the need for operator access, system monitoring, and remote controls.

As a familiar analogy, a microgrid control system development process can be considered similar to the design and development of a protection system. Both processes have very similar characteristics, including the criticality of the functions, reliability and dependability requirements, system coordination needs, and numerous choices among commercial schemes to implement various processes. Yet protection system manufacturers have been able to standardize the functions and offer off-the-shelf products that can be obtained from various vendors and implemented by system designers selected by the owner as the preferred engineering team. It is always understood that there are certain proprietary techniques in the design of the protection functions, and for that reason, vendors' supporting roles in the deployment process are key considerations in selecting a product or preferring one vendor over another (based on the performance requirements and complexity of the system). However, during or after implementation, the system in use can be fully configured, expanded, and reapplied by selecting functions and schemes from given libraries within products through training with in-house or external expertise, with some or little involvement of vendors.

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The aim is that by applying standardization and incorporating interoperability methods in communications and data exchange among devices, at least the core microgrid control functions can be offered as predefined control blocks residing in off-the-shelf products, which are selectable and programmable by users.

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