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Microgrid Implementation Challenges and Key Technologies

by Jacques Philippe
Patrick Beguery
Philip Barton

Executive summary

Microgrid implementation and project challenges vary according to requirements and economic and business drivers, but on a broader level can be developed using a common approach. This paper identifies the main challenges faced during a microgrid project implementation and provides practical information for addressing them.

The microgrid system

Microgrids are formed from the association of components acting in a coordinated manner, rather than from a single technical brick. Most of the time, they are composed of:

a) An energy network infrastructure that includes equipment for energy generation (usually multiple distributed energy resources (DERs)), energy distribution network(s), and energy users/consumers of different criticality levels and profiles
b) Sensors and meters
c) Controls at the DER level
d) Controls at the microgrid level, aimed at best managing the entire system
e) SCADA system to interface with microgrid operators
f) Cloud-based services such as tariff management, demand charge optimization, demand response, self-consumption management, blackout management, CO_2 reduction, etc.

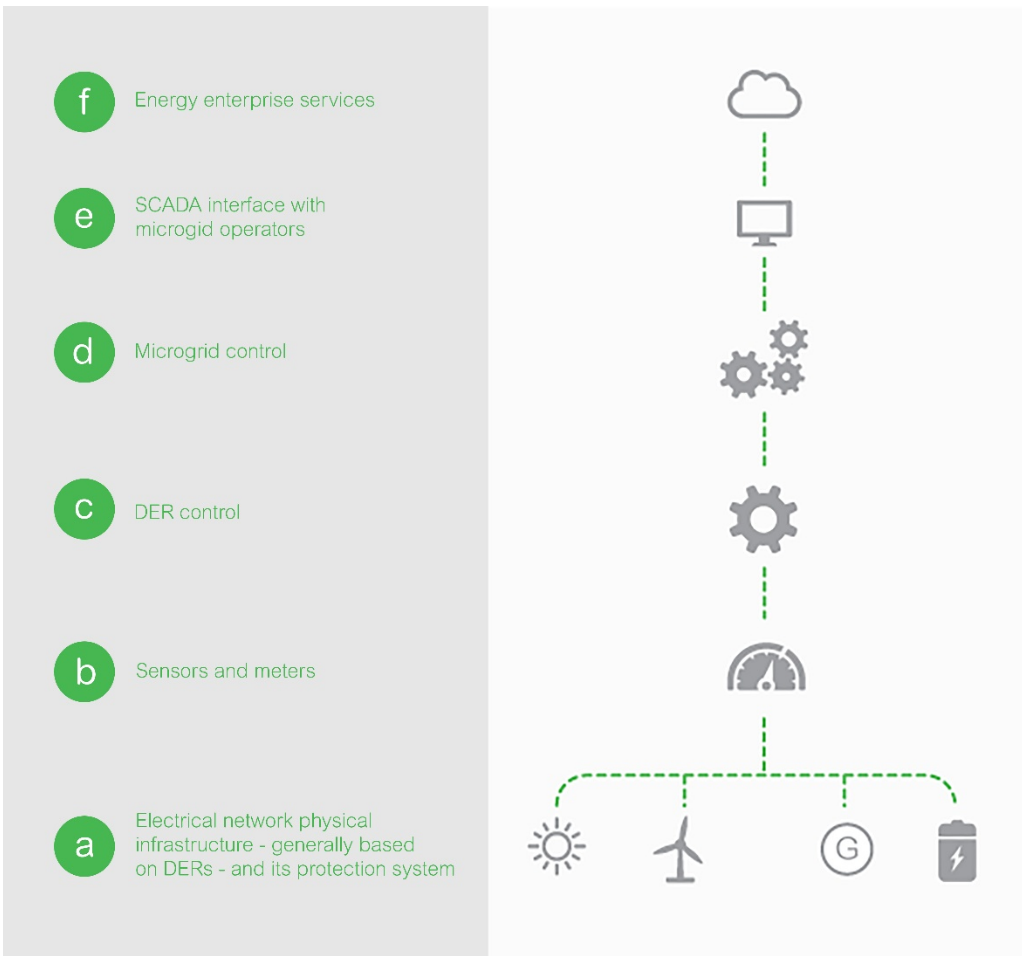

Figure 1

The microgrid functional architecture, from the grid to the cloud

Microgrids are implemented to fulfill global expectations such as resiliency, economy, security, and CO_2 reduction. The relative importance of these expectations depends on the microgrid category, which is determined by the connection to the main grid (grid connected or off grid) and type of ownership (utility or community). The related technical features and components might differ accordingly.

In real life, microgrid opportunities and projects will always differ in their business model and commercial context, in their actual environment, and in their technical content and scope of work. This paper emphasizes the main challenges faced during a microgrid project implementation and provides practical information for how to address them.

Figure 2

Microgrid project process

Preliminary sizing

Once the business model to follow is clear, taking into account the typical architecture and technology challenges, some specific preliminary sizing is necessary to understand and define a project's economic viability and then propose appropriate technical solutions.

Each microgrid project varies in size, power and voltage levels, number and type of distributed energy resources as well as number, type, and criticality of electrical loads, etc. The environmental information (such as location, climate, standards and regulations, local energy pricing, physical layout, main drivers and cost criteria, etc.) is always project specific and highly influences the solution's design.

Therefore, the preliminary sizing step aims to model the actual physical and economic environment and context in order to help the engineering team determine the types and power ratings of the microgrid components to be used, so that a given cost criterion is minimized. Also, the preliminary sizing must take into account a number of incentives that will play a key role in the feasibility of project.

This step generally requires a microgrid sizing software tool that enables the following:

- Selecting cost criteria: CAPEX, OPEX, net present cost, return on investment, LCOE[1], CO2 emissions, renewable penetration rate, and sometimes a mixture of these
- Defining the technical perimeter to cover (assess the list of available components and level of details in the entity's existing computer models)
- Using model libraries with a related database of typical parameters (physical and commercial)
- Modeling different control strategies and evaluating their benefits

Several tools for this exercise exist, HOMER Energy being one of the most widely used. A common critical limitation of these tools is that they do not allow the user to define global control strategies. To overcome this limitation, energy management solutions vendors develop dedicated tools for their energy solution architecture and software, e.g., Esyst software developed by Geli. In parallel, more open approaches are being studied by some academic and industrial research centers and start-ups.

[1] The levelized cost of electricity (LCOE) is a measure of a power source that attempts to compare different methods of electricity generation on a comparable basis. It is an economic assessment of the average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime.

Design engineering challenges

Once one or several economically viable scenarios have been determined in the preliminary sizing phase, some project-specific engineering studies are required. These will both specify equipment details and guarantee the correct behavior of the microgrid while in operation. Below is a list of the main calculations and studies to perform.

1. Identification and **detailed description of the operating philosophy with all the operating modes** of the microgrid: Every source-versus-load scenario shall be identified and described, even the temporary configurations, for example when switchovers or emergency shedding are required. This step is particularly important because microgrids generally involve many types of electrical sources of different natures and behaviors.
2. **Load flow calculations** in all possible operating configurations: The goal of this iterative work is to evaluate the current flows and the voltage levels in the microgrid's power system while in operation, allowing:
    - The identification of any risk of equipment overload
    - The identification of (and forbidding of, whenever relevant) any configurations incompatible with the current and voltage constraints
    - The recommendation of any preferred transformer taps and/or size of any power factor correction (PFC) equipment in order to achieve an acceptable voltage plan (according to self-operation requirements as well as grid code requirements whenever applicable)

    In microgrids, establishing a relevant load list and assessing the load criticality levels and load consumption profiles are sometimes a challenge.
3. **Short-circuit current calculations:** The goal is to determine the minimum and maximum short-circuit current levels that may occur in the power system in case of a fault. The use of international and local applicable standards is highly recommended (e.g., IEC, EN, IEEE, etc.). Those short-circuit current values allow for:
    - The correct sizing of power system equipment in terms of thermal and dynamic current withstand ratings
    - The definition, settings, and coordination of the power system's protection relays and functions

    In microgrids, short-circuit currents are likely to vary substantially between different operating configurations, due to their multi-source design.
4. **Protection philosophy and coordination study:** Considering the low and variable short-circuit currents of microgrids, the protection study is a key engineering step. This study is designed to ensure personnel safety and equipment protection, as well as to coordinate the protection tripping sequences and curves. In microgrids, traditional protection principles may not apply easily, and innovation and compromises in this area is often necessary.
5. **Neutral earthing system management:** Related to the protection study, this technical topic is crucial to ensure the correct operation of microgrids, especially because microgrids often switch over from one source to another, and combine electrical supplies from the main power grid, rotating generators, and static converters. Because electrical installation rules are often specific to local regulations, the management of how the neutral is connected to earth then distributed within the microgrid can become challenging.
6. **Dynamic stability studies:** It is very important to evaluate, predict and monitor the dynamic behavior of the microgrid's power system with regards to transient events. Those events can come from:

- Normal operation: Load step, transformer inrush, motor starting, load shedding, transfer between one operating mode to another, source switchover, etc.
- Unexpected disturbances: Loss of a power source or short-circuit fault on a power system component

Microgrids generally include a mix of power generation, storage and static conversion technologies. The challenge is to ensure stable conditions with not only rotating inertia given by traditional generators, but also PV, wind and Electrical Energy Storage System (EESS) static converters. With the increasing number of power electronic-based generation, as well as new types of converters such as Virtual Synchronous Generators (VSGs), stability studies should be carried out with close links with the static converters' control system designers and manufacturers.

7. Electrical equipment specifications and single line diagram (SLD): These deliverables are the main outputs of the power systems engineering studies. They are key elements required to order equipment, and they are complementary to the first item on this list: explaining and illustrating the microgrid operating philosophy.
8. Microgrid control systems – functional analysis and design: The microgrid control systems are an essential element to make microgrids fully operational. From the detailed description of the operating modes (see item one on this list "Explaining and illustrating the microgrid operating philosophy"), functional analysis, complete development (or adaptation) then configuring the microgrid control system are required. These control systems shall integrate all possible control schemes and operating scenario management.
9. Energy management optimal settings and robustness analysis: The same energy models that have been used in the preliminary design can be reused to perform more detailed work and services. Most energy control solutions include multiple tuning parameters, and simulation can be used to identify the optimal value for some of those parameters, taking into account potential uncertainties and specific events (which are not necessarily considered by preliminary design tools).
10. Microgrid testing and commissioning: A comprehensive testing and validation specification shall also be written to check that in any actual situation, the microgrid controller provides the expected behavior and decision– based on the selected criteria and the actual constraints. Interoperability with upper–and lower–layer systems must be specified and tested prior to going live.

Note: A majority of power system engineering studies can be performed with computer simulation tools available on the market today. For stability studies, the main challenge for those software tools is to embed detailed control models of power converters and machine regulations, or at least to allow for coding new control strategies then testing them in the tools' environments and languages.

Transitioning from design to operation

Although microgrid operation in itself is out of the scope of this paper, it is useful to understand that certain computer tools used during the design phase(s) can be reused during operation. This is especially true for the microgrid computer simulation models that can provide additional service opportunities, such as:

- Operator training: A new operator can use simulation to learn about the behavior of the microgrid in various conditions and following certain events (e.g., how the protection will react in the case of a fault in different grid configurations).

- **Performance follow-up and fault detection:** Using simulation tools to produce expected signals, then comparing those to real ones allows the detection of gaps between the computer model and reality.
- **Operator-assisted operation:** In the same way as for operator training, simulation can be used to run what-if scenarios before making decisions about operation optimization, as well as to anticipate any consequences after specific events. This includes not only day-to-day control configuration changes, but also evaluation of the impacts of any upgrade or extension of the microgrid infrastructure (e.g., how a new load profile would change the microgrid's asset usage and performance; or if energy rates change, whether it would be beneficial to change or add new energy assets, etc.).

Conclusion

Microgrid technologies and solutions are already available, reliable and efficient, and there are many examples of successful implementations. However, microgrids' rapid and large dissemination still faces challenges, which could be related to the struggle in managing projects that involve new actors, with new business models, new functional demands, and technical constraints. The answer for improvement includes the use of new tools and a precise methodology for sizing the microgrid, conducting specific design calculations, and studies toward an efficient implementation.

About the authors

Jacques Philippe is the Power Systems Competency Domain Leader for Schneider Electric. He is also in charge of a power systems expertise team at Schneider Electric's regional execution center for the EMEAS region. He holds master's degrees in both electrical engineering and in signal/image processing from the Grenoble National Institute of Technology (INPG), France. In the last 12 years, he has been involved in various customer project tendering and execution in different market segments, mainly linked to the electrical engineering field. With a core team composed of representatives and experts from across the entire Schneider Electric organization and its geographies, he leads the roadmap definition for the company in the power systems domain.

Patrick Beguery is part of Schneider Electric's Analytics, Applications and Programs team, leading the simulation expertise. After 10 years working for Renault, the French auto manufacturer, he joined Schneider Electric in 2007 to work on simulation for building, district and microgrid segments, both to support research and development and provide tools to facilitate the design and operation of customer-specific solutions. He is currently involved in the development of design and sizing tools for microgrids. He also leads the BEES community, which bring together experts in simulation for different segments.

Philip Barton leads Schneider Electric's North American strategy around organizing microgrid projects and solutions, both internally and externally with partner companies. Since 1998, Philip has led Schneider Electric teams in retrofitting entire microgrids or any part of their enabling technology, including distributed generation, power equipment, engineering services, inverters, metering, software, and power controls.