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Community Microgrids – Operational and Maintenance Considerations Governed by Technology Selection and Control Systems

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SUMMARY

Driven by recent major outage events and extended recovery time after natural disasters, Microgrids have become very popular worldwide for enhancing reliability and resilience of power systems. A key characteristic of microgrids in the context of reliability and resiliency use cases is the outage duration (or load serving capability) which requires multiple days of autonomy - 2 to 3 days at least). Although the aim is to increase the renewable energy content of microgrids, a combination of conventional rotating-machine-based generation units (CGUs) and inverter-based resources (IBR) would be needed to serve load for multiple days. However, the generation mix will increase complexity of control and protection as well as operation and maintenance (O&M) procedures. Hence, optimizing O&M cost of the microgrid while maintaining maximum load serving duration and providing proper power quality and reliability to the microgrid customers are major considerations in design and operation of such microgrids.

This paper utilizes experience gained from real-world deployment and operation of two microgrid systems in the Canadian utility context to assess operation and maintenance considerations and provide guidelines that should eb considered during the microgrid design and implementation stages. The two benchmark microgrids are analysed from the design-related provisions and selection of proper sequence of operation (SoOp) that directly impact microgrid O&M and its effective life of the system. The focus is on balancing the use of solar plus storage, versus the CGU. Several unique microgrid control features and applications are introduced and evaluated to determine whether the specific microgrid controls (MGC) are well geared toward optimizing both fixed and variable components of O&M costs.

KEYWORDS

Microgrids, Distributed Energy Resources (DER), Sequence of operation (SoOp), MGC

1. INTRODUCTION

Microgrid has recently gained a lot of attentions by industry, mainly as a result of growing frequency and duration of outages caused by natural disasters (e.g. storms, flooding, and wild fire) and the need for increasing power system reliability and resilience.

Resiliency is defined in this paper as the extent of which a system can recover form a planned or unplanned disturbance to minimize or eliminate the impact on customers for their intended business. In the context of a microgrid, resilience may be reflected in the sizing of the resources for extended outage, plus providing redundancy for loss of generation. Furthermore, use of automation and optimization schemes to increase efficiency of operation and provide alternative paths for supplying customers. Other features to enhancing reliability and resilience are related to incorporating fail safe schemes and applying condition monitoring and preventative maintenance.

While the existing circuit topography in many urban areas 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 point of interconnection (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. In addition, to fulfil the resilience definition, incorporating operation and maintenance (O&M) considerations of a microgrid becomes a key determinant factor for microgrid controller (MGC) design.

The focus of this paper will be on utility-integrated microgrids. Design of a microgrid for a utility environment requires a much deeper dive into the planning and operational aspects of distribution systems. One key argument is that enhancing reliability and resiliency of a microgrid will add to the complexity of the design. Unless the operation and maintenance of a microgrid is not properly reflected at the design and development stage, the microgrid may fail to meet the intended design and performance objectives.

2. MICORGRID TYPES AND DEVELOPMENT STAGES

Microgrids can be grouped by customers (or users) types and ownership of key assets. The two widely discussed microgrids are:

a) **Community microgrids**, in which the microgrid point of interconnection (POI) is in front of the meter (FTM), or on utility side of the customers' assets but behind of the meter (BTM). In this type, microgrid resources serve multiple customers through distribution lines and assets generally owned by an electric utility company – commonly called Area EPS owner.

b) **Customer microgrids**, in which the microgrid POI is behind the meter and microgrid resources serve facilities (or loads) owned by one customer (or one legal entity).

Additional attributes and differentiations for the two microgrid types are listed in Table 1, describing boundary areas, ownership considerations, and benefit drivers for developing microgrids.

Table 1 - Microgrid types and attribues

Attribute	Community (Utility-scale) Microgrid	Customer Microgrid
Boundary	• Multiple customers on single or multiple feeders • Multiple DERs: Front or Behind of the Meters	• Single/multiple facilities under one account (customer) • Behind the Meter (BTM) • Exports power to the area EPS
Ownership	• Utility owns the distribution assets • Utility operates the MG (Island) • Third-Party owned DERs	• Customer owns and operates all the asset • Interconnection requirements to be met • Utility may control PCC of DERs
Drivers	• Reliability, Resiliency, Decarbonization	• Energy Cost Saving, Reliability,

The microgrid development phases includes conceptual design, preliminary design, engineering and development, construction, and operational use and system support phases. Figure 1 shows different stages of development and the key milestones for each stage. Stage 1 primarily deals with planning aspects of a microgrid. The outcome of this stage is a conceptual design and feasibility analysis that also provide information on DER sizes and technologies included in the microgrid. Basic studies for equipment selection and microgrid interconnection assessments are covered in the Design stage to prepare for stage 3, which will cover contracting, engineering, procurement and construction. Specific studies associated with engineering of microgrid such as grounding, arc flash, and short circuit analysis will be provided in this stage; however, most inputs for the engineering and equipment specification development (for procurement) are expected to be available and previously addressed in stage 2.

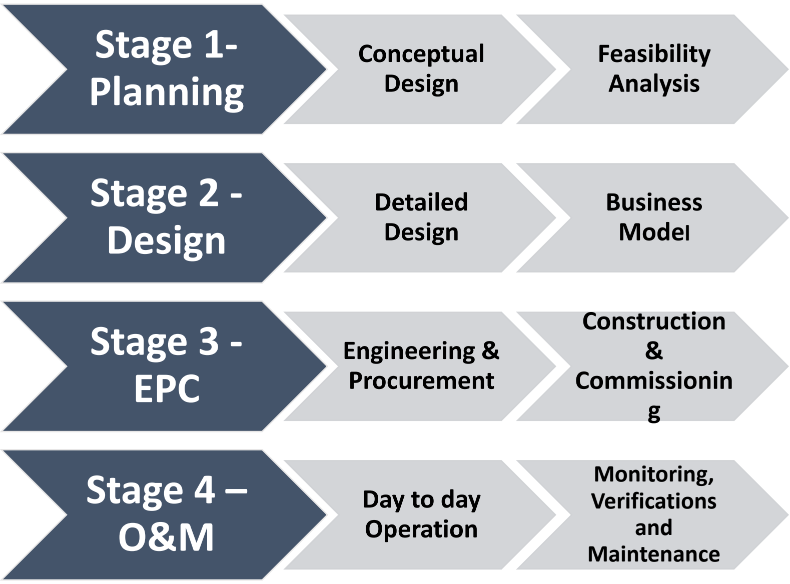

Figure 1. Microgrid Development Phases

For a successful microgrid development, prior to initiating microgrid detail design, it is recommended to prepare and agree upon a functional specification document to explain sequence of operation for a microgrid.

2. Sequence of Operation – "Begin with End in Mind"[1]

Sequence of operation (SoOp) for a microgrid directly influences the design and selection of various technologies, including DER types and control capabilities. Hence, it is strongly recommended to first prepare a SoOp for the microgrid, discuss with stakeholders and agree on various aspects of SoOp before getting too far into the MGC vendor/technology selection or detail design - that means SoOp development and approval should be initiated in early time of Stage 2 in Figure 1. It is even more beneficial to hold preliminary discussions in the planning stage and prepare a high level SoOp and operation considerations based on the conceptual design.

SoOp defines a series of operating states and conditions for changing those states to cover all modes of operation for the operating cycle and life of a microgrid. In general, microgrid has three (3) steady-state (continuous) modes and three (3) transitional modes.

Steady state modes of operation are:

- Grid connected,
- Islanded, or
- De-energized (blacked out).

Transitional modes of operation are:

- Transition to islanding
- Transition to grid connected (re-connect)
- Tripping out, which is transition form any of the two energized states to a disconnect (de-energized) state

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[1] A constructive quote from Stephen Covey

Figure 2 and Figure 3 show two different perspective of microgrid sequence of operation, here called: basic and advanced SoOp.

A basic SoOp for a microgrid may include the following states:

1) During a grid connected mode of operation: DERs are in standby mode, maintaining state of reserve energy (SOC), or completely turned off (no dispatch)
2) When a fault or any intolerable disturbance happens, microgrid gets disconnected from the grid (generally using anti-islanding type schemes at POI) and supplies microgrid load. The islanded load of this microgrid could be the entire load or a subset, which is normally called critical load
3) In the islanded mode, if the microgrid runs out of energy or losses DERs, it will trip out and goes to black out (disconnect mode)
4) Once a grid healthy condition is qualified, microgrid switches back to the grid connected mode to supply entire load.

Note that for remotely located community microgrids that are not integrated to an area electric power system, any central diesel/gas generator plant or a hydro power plant would play the role of the grid for the grid-connected mode - that genset plant will be the permanent source of power for the community, acting as the grid.

The basic SoOp described above is dominantly used for customer type microgrids that has only an ESS or has solar plus storage and need to supply critical load.

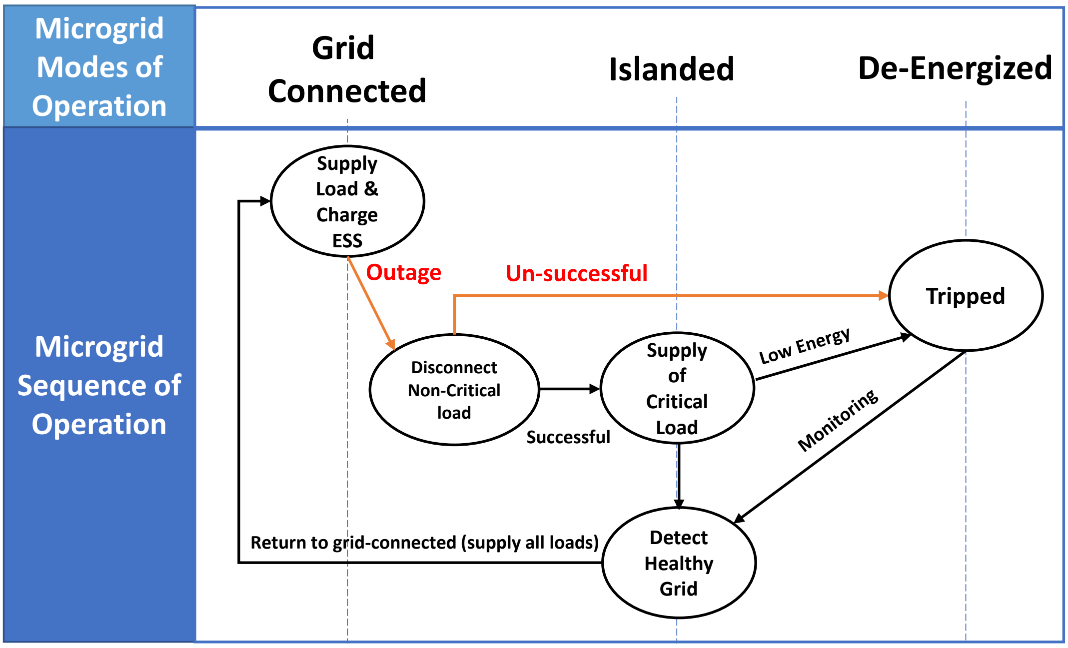


Figure 2 - Basic SoOp for a microgrid with only an ESS, supplying critical load

An advanced SoOp may include several sequences based on provisions for microgrid responding to various system conditions such as interna/external faults for extending islanded duration, or it could also cover advanced functionalities such as reconfigurations or clustering of nested microgrids.

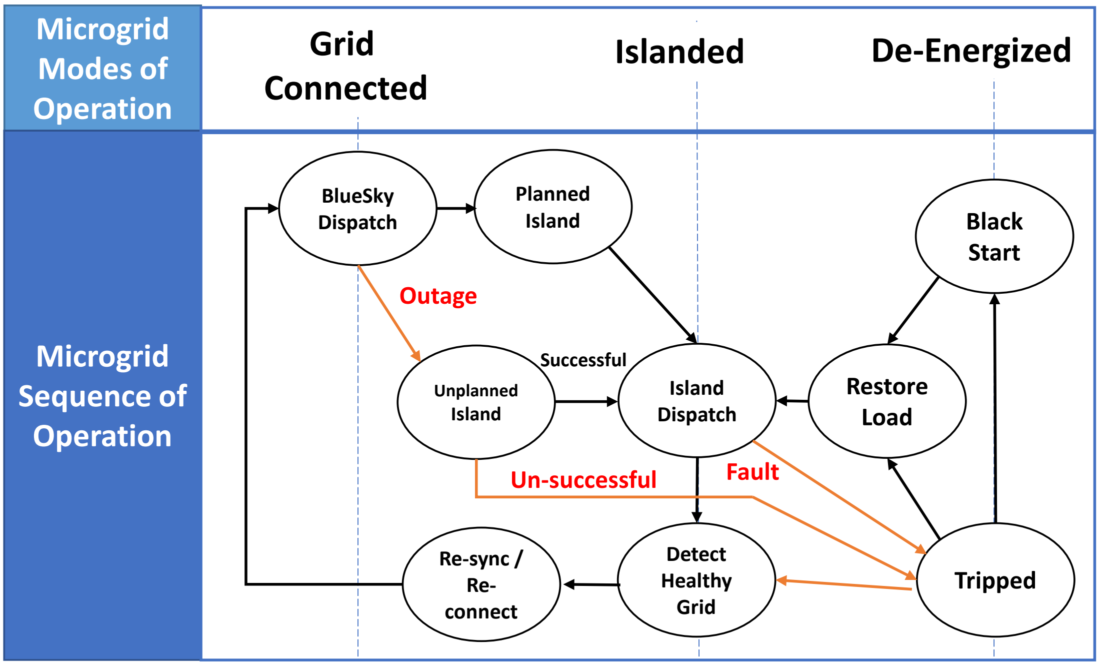


Figure 3 - Advanced SoOp for a community type (utility-scale) microgrid with multiple DERs

Other special SoOp aspects that could influence a microgrid design are:

- Blue sky dispatch (or optimization) for performing various grid support or ancillary service applications
- Synchronization methods: passive or active methods
- Load restoration schemes and sequence
- Load curtailment sequence and priorities
- Response to internal faults (n-2) during islanded
- Energy storage control applications for grid connected (such as maintain SOC) or in islanded mode
- And similar ones.

In the following sections, two microgrid benchmark systems are defined and their sequence of operation are described to explore and highlight operation considerations that were incorporated in the overall design of the microgrid.

3. FORT CHIPEWYAN MICROGRID – Alberta, Canada

The Fort Chipewyan microgrid was constructed as a mission critical project in response to a delicate scenario. The about 800 inhabitants, who are mostly of first nation origin, were very close to not having electricity for a large portion of the year. The original plant contained 4 diesel generators and 12 diesel tanks. The utility integrated a large photovoltaic (PV) generation facility with a battery energy storage system (BESS) and a decentralized microgrid controller and did so economically and postponed the need for major system improvements for many years. The challenges and solutions are explained in more detail in this section.

3.1. System loading and diesel shortage

The system loading had experienced unprecedented growth over the years preceding this initiative. A historic yearly consumption data for both feeders combined, as recorded in 2017, is shown in Figure 4. The data displays the typical load profile of a northern community, with higher consumption during fall and winter, and lower consumption during spring and summer. During warm summer days, the load is sufficiently low that only one diesel generator unit is enough to supply the entire community, while during dark winter nights the three diesel generators run simultaneously.

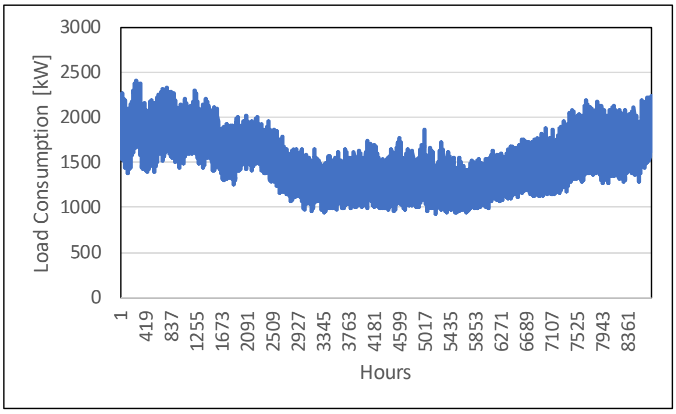


Figure 4. Historic yearly total load supplied by the system

The community had been experienced unprecedented load growth, supporting municipal infrastructure upgrades such as the uprate of three sewage lift stations, a refurbished waste water treatment pumping system, and a new recreational center. A load growth sensitivity analysis was completed until 2023 and is shown in Figure 5. Three forecast levels were produced, all of them suggesting a substantial and consistent growth.

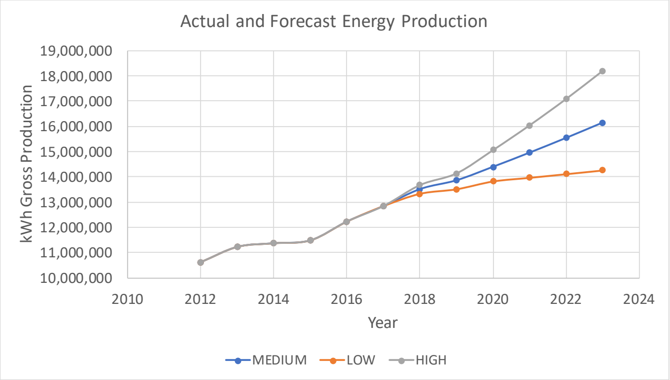


Figure 5. System load forecast as of 2017

Historically, the community has only been accessible by an ice road in the winter, for an average of 6 weeks when the formed ice is sufficiently strong to support refueling tankers. The plant only contains 12 diesel tanks, with total storage of about 3,300,000L capacity. In 2017, the community consumed 3,185,000 L and in 2018, 3,294,000 L. This projected load growth reveals that the diesel storage capacity would soon be insufficient to supply the community between times refueling is possible.

3.2. THE MICROGRID BEGINS TO GET BUILT

In response, the electric utility has spearheaded planning efforts that employ two PV farms. In 2019, a 450kWac/600kWdc plant was commissioned to offset some of the load consumption and relieve the critical scenario. This size was chosen to optimize the diesel savings to offset the immediate shortage of diesel storage and to ensure system frequency stability [1]. To further address the issue of diesel storage, a larger solar farm, sized 1.9MWac/2.2MWdc was installed in the second stage of the project. This amount of generation is very large as compared with the historic minimum system load. To manage the PV size, the utility has also employed a 1.8MW/1.6MWh BESS, as well as a microgrid controller. These components are illustrated in Figure 6. The reasoning for choosing a combination of PV and BESS, as well as the sizing optimization exercise, was presented in [3] and is outside of the scope of this article.

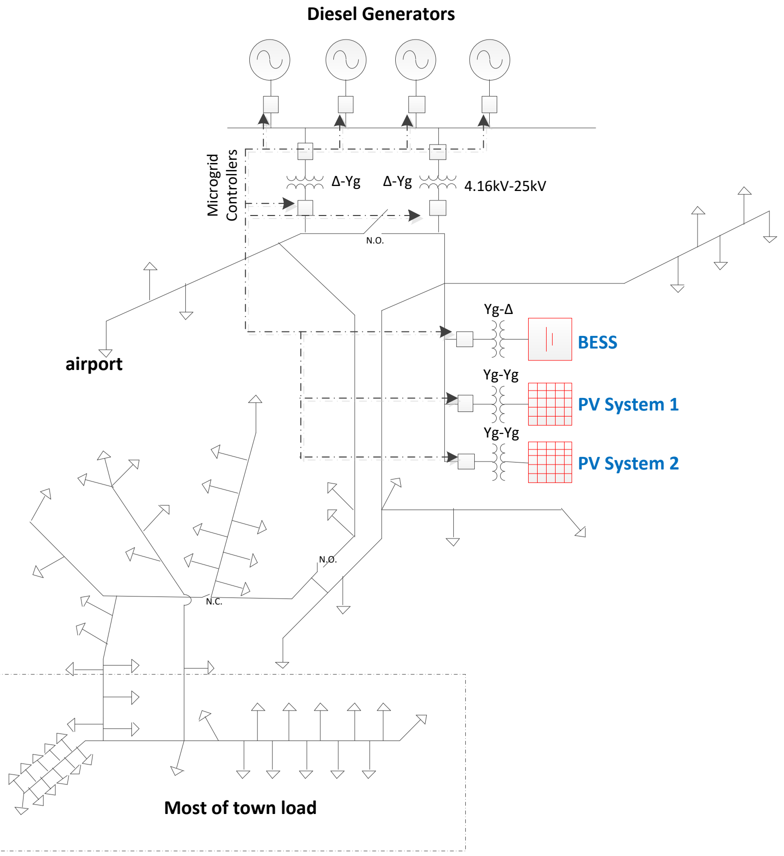


Figure 6. Simplified topology of the system under study.

The architecture of the microgrid controller is as follows. Each of the indicated components in Figure 6, namely each of the four diesel generators, the main feeder breakers and reclosers, the PV systems and the BESS, were supplied with a decentralized microgrid controller, represented by the dot-dashed lines. This allows a high degree of system visibility and controllability. Figure 7 show the corresponding SoOp for this system that was instrumental in the development of the microgrid controller. Note that in this case, the diesel plant represents the grid-connected state of the system.

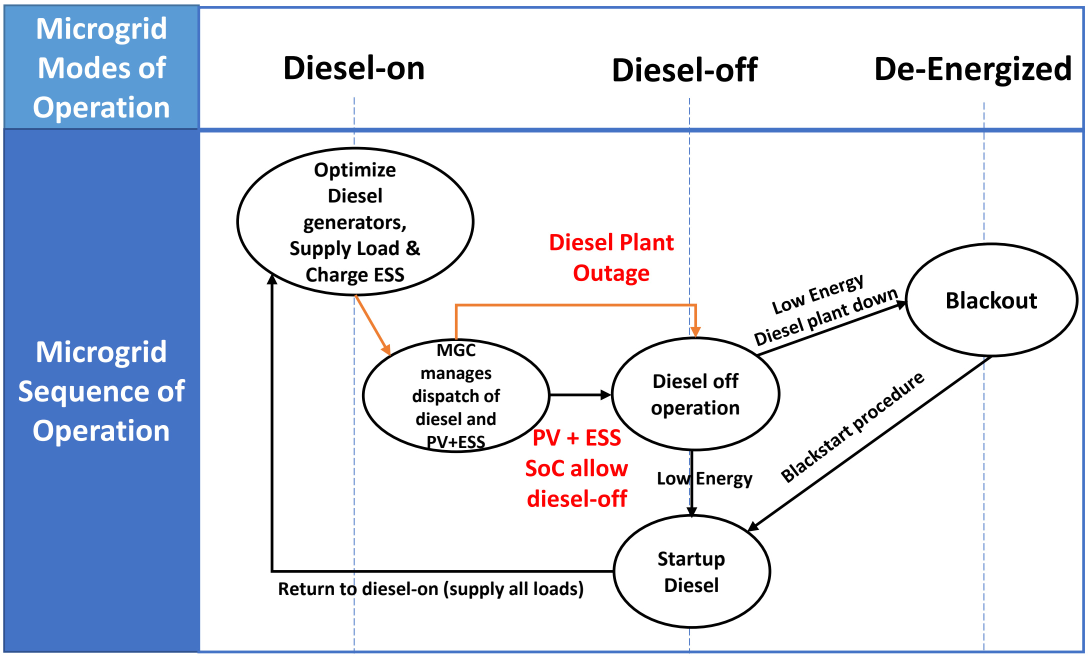


Figure 7. SoOp for the remote community microgrid (system 1)

The distribution system is supplied by four diesel generators, each of which rated 1.15MW/1.29MW/1.41MW (nominal/prime/overload ratings). The electricity in the plant is then stepped up via two 4 MVA Δ-Yg, 4.16kV-25kV transformers (Δ on the 4.16kV side). The distribution system comprises two 25kV feeders, which supply some load near the plant and emanate about 8km south, where they supply most of the town load. Both feeders have a continuous Multi-Grounded Neutral (MGN).

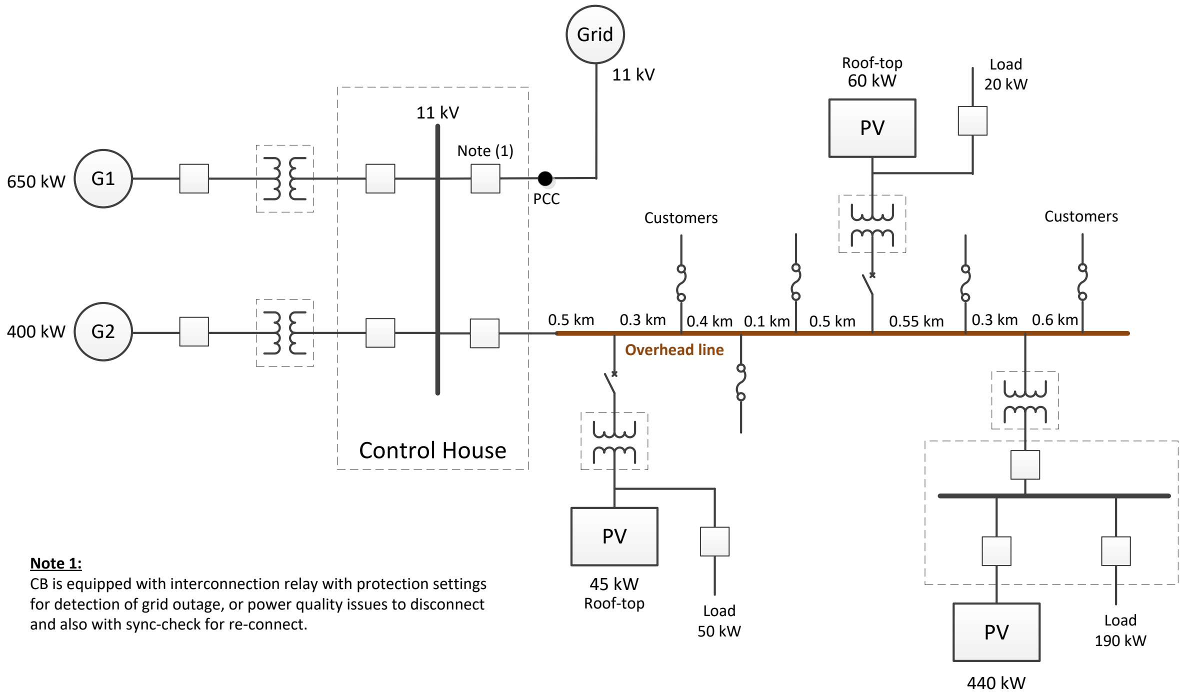
The solution has been shown to save the amount of diesel projected in the planning studies [2], or about 25%. The utility very successfully arrived at a scenario where no new diesel tanks will be required for many years, providing a cleaner and more reliable supply to the community residents.

4. REMOTE MICROGRID WITH A WEAK GRID CONNECTION

Figure 8 shows the schematic of a remote microgrid – built in one of the Northern Canadian first nation territory to serve a local community through a short overhead powerline with multiple sections. The community power system has a grid connection point through an old existing power line, but because of the long distance over a relatively low voltage (11 kV) and passing through a very rough mountain trail, the connection is very unstable and unreliable. Large voltage and frequency excursions are very common on the grid connection that can harm the customer appliances, especially during the peak load period, causing significant voltage drop across the line. For that reason, two diesel gensets (1050 kW in total) were added at a local generation center to manage customer supplies during the power outages and when the grid is tripped offline because of poor power quality using a local protection relay scheme against large over/under voltages and frequency deviations.

4.1 THE MICROGRID TOPOLOGY

To improve voltage quality and increase stability of the grid, a 500 kW, 2-hour battery energy storage system (BESS) was proposed to be installed at the local generation center connecting to the same grid bus of the diesel gensets at Point of Common Coupling (PCC)), which is the same as POI for this system, since all generation are connected to the same location as the grid is. The use case for BESS also incorporated diesel fuel minimization and preventing backfeeding from the several distributed PV systems along the distribution system, installed by customers over time, from which the interest for adding more PV systems is also growing by time.



Note 1:
CB is equipped with interconnection relay with protection settings for detection of grid outage, or power quality issues to disconnect and also with sync-check for re-connect.

Figure 8 - Schematic of System 2

The primary microgrid use cases are:

- Outage management during grid power quality or line down,
- Reduced diesel fuel consumption using BESS that can capture excess power from PV systems or perform very slow charge overnight through the weak grid connection,
- Voltage management for improving local grid stability (preventing large excursions) when operating in grid forming mode,
- Prevent backfeeding to the gensets while increasing renewable generation, and
- Improving overall efficiency of the community energy systems, through coordinated operation of genset, BESS and distributed load for offsetting power import from the weak grid (minimizing losses for power delivery over a long distance).

Table 2. System 2 Load and Generation Specifications

Energy Center	Generation	Load	Unit
Distributed PV rating (total)	545		kW
Daily average PV production	1915.675		kWh
BESS	500 / 1000		kW/kWh
Diesel Genset	1050		kW
Light Load		230	kW
Peak Load (connected kVA)		680	kVA
Minimum Daily consumption		2280	kWh
Maximum Daily consumption		9010	kWh

The load and generation specification of the microgrid is shown in Table 2. Note that system peak happens during cold winter days, since electrical heating accounts for majority of load. It is very clear that during light load condition of the community, there is a major chance of reverse power flow and backfeeding to genset if the main grid and BESS are not present. On the other hand, it is evidence that optimizing the energy use through combination of BESS and distributed PV has the potential to reduce the power import from the grid, bring it close to zero for most summer days. However, the design of the microgrid control system can be selected to maximize reliability or efficiency, but not be able to achieve both at the same time. This challenge is further discussed in the following section.

4.2 MICROGRID CONTROLS AND SEQUENCE OF OPERTION

To achieve the objectives of the microgrid, the following control functions need to be implemented for both grid-connected and off-grid (islanded) operation:

- Power exchange function: reducing the power import or any export from/to the electric grid to minimize losses and stability concerns,
- Load and generation balancing function: extend the use of solar + storage for supplying the island duration and operation without the use of diesel generators,
- Genset cycling function: coordinate start up, paralleling, cycling, and power sharing among the genset and in consideration of BESS state of charge,
- BESS startup and sync function: start BESS in grid forming mode and synchronize with the operating community microgrid through genset or the main grid.
- BESS state of charge control function: coordinate the time of charge for BESS based on load and availability of solar power production, or initiate genset cycling function if SOC too low and there is very low PV production or high load expectancy,
- Voltage and frequency control: operating the BESS in a grid forming mode all the type to react to sudden changes in the load and solar variability to stabilize the system,
- PV curtailment: Limit the PV production, if needed, when BESS is closed to be fully charged (e.g. SOC above 80%) and load forecast is light,
- Black start function: Restore the microgrid after complete blackout through gensets or BESS,

- Synchronization function: re-synchronize the microgrid with the electric grid at PCC and reconnect.

To ensure the control functions properly reflect the expected operation and maintenance of the system 2, an overall sequence of operation for the microgrid were developed and discussed with stakeholders. Two SoOps are proposed.

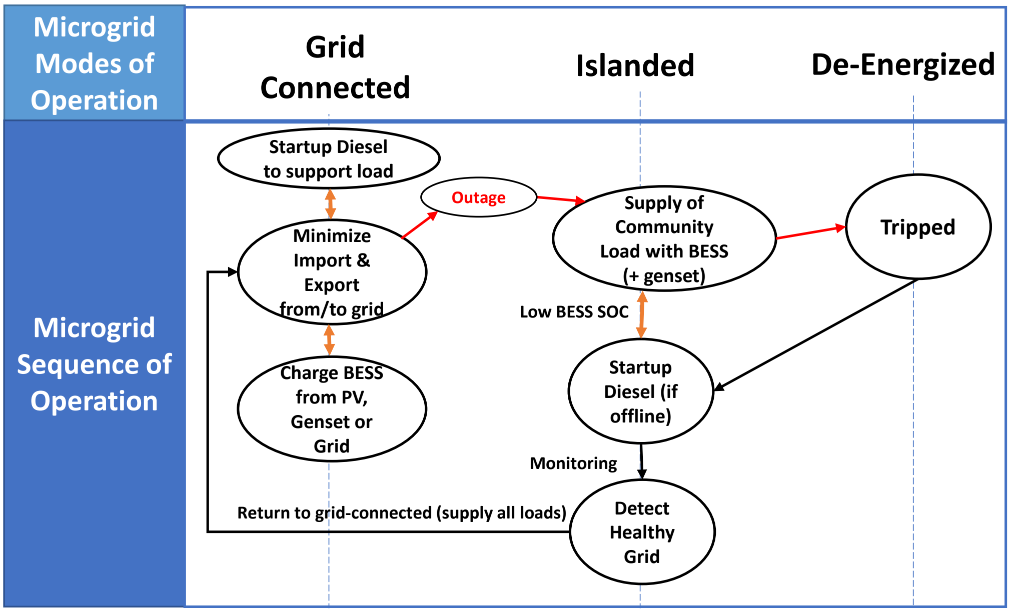


Figure 9. SoOp for maximizing efficiency and minimizing diesel fuel use

Design for maximizing efficiency and minimizing diesel fuel use: Figure 9 shows the sequence of operation with the assumption that none of the diesel gensets will be in service during the grid connected mode. In this case, BESS will not be able to always bring the power exchange at PCC close to zero – for instance during a cold cloudy day that load is close to peak and there is not much PV production. The BESS charging period is also limited to excess power from PV and any timeframe with light loading of the community (e.g. at night). This will expose customers to potential momentary outages if the main grid has any power loss and BESS is not capable of carrying entire load (and there was significant power mismatch at PCC prior to outage, causing large transients and stability challenges).

Design for maximum reliability: For this design, a diesel genset should be brough online at heavy load condition of the community and/or anytime that BESS SOC is low and cannot reduce power exchange at PCC. Because of this operation preference, the diesel genset utilization will be relatively higher than the previous case, which requires detail analysis of the load curves and generation dispatch to select the BESS size properly. The difference in sequence of operation for this case is shown in Figure 10. Note that, when a diesel genset is in service, the genset loading should be at least 60% of the genset rating. The additional excess power needs to be absorbed by BESS. From the analysis of the community load, the peak load durations are less than 100 hours, which become manageable within the typical permitted annual operation of a diesel genset. Otherwise, increasing size of BESS is an option.

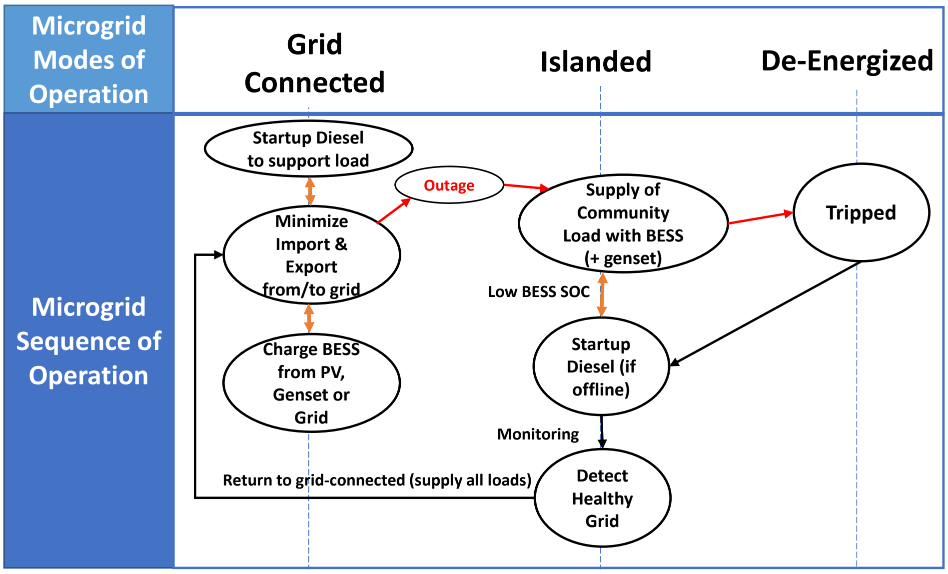


Figure 10. System 2 SoOp for maximizing reliability benefits

5. CONCLUSION

Considering the growing interest and focus on utilizing microgrids for enhancing community reliability and resilience, it is important to ensure operation and maintenance of microgrid are well thought about and reflected in the control system design. The experience and observations from several recent microgrid project have shown that the push for reducing cost of a microgrid project by cutting engineering and development effort required for design of a proper controller can adversely impact the greater attention to the details of microgrid operation and consequently the microgrid operation reliability and dependability expected by customers. This paper has reflected on a systematic process to consider operation and maintenance of a microgrid more seriously in the design and development stage. Sequence of operation (SoOp) for a microgrid directly influences the design and selection of various technologies, including DER types and control capabilities. Hence, it is strongly recommended to discuss and prepare a SoOp for the microgrid in the very early stage of a project, engage the stakeholders in the discussions to agree on various aspects of SoOp before getting too far into the detail engineering of the microgrid or outsourcing the controller development effort. Two SoOp examples were discussed in the context of existing microgrids and field experiences.

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