Advanced Grid Research
OFFICE OF ELECTRICITY
US DEPARTMENT OF ENERGY

Compendium for Voices of Experience

MICROGRIDS FOR RESILIENCY

Microgrid Controller Performance Specifications

Developed by Southern Comp ny’ R ese r ch and Development Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Smart Electric Power Alliance

NOVEMBER 2020

Prepared for the U.S. Department of Energy by National Renewable Energy Laboratory under contract No. DE-AC36-08G028308, Subtask OEPG.10294.03.01.09 in conjunction with the Smart Electric Power Alliance under subcontract, SUB-2020-10032.

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Abbreviations

ABBREVIATION	DEFINITION	DESCRIPTION
MGC	**Microgrid Controller**	The entirety of the microgrid controller system, including device-specific translators
PCC	**Point of Common Coupling**	Point of interconnection between the microgrid and the grid
DER	**Distributed Energy Resource**	A generation asset available to the microgrid
PV	**Photovoltaic**	Solar array
ES	**Energy Storage**	Battery
V/f	**Voltage/frequency**	A means for providing Voltage and frequency regulation for the microgrid when it is operating in an islanded fashion (i.e., not connected to the main grid)
P/Q	**Real and Reactive Power**	An operation mode designed to dispatch real and reactive power based on setpoints

Microgrid Controller Operations

The overarching goal of a microgrid controller's (MGC's) operational capabilities is continuous, non-interrupted power for the load such that there is no loss in power during on-grid, off-grid, or transitional states of the PCC and to enable the optimal dispatch of generation resources during normal operation based on price, weather, and load forecasts. Islanding and Resynchronization of the microgrid can be accomplished either by direct control
of MGC's user interface, through a remote network request from the control center, or automatically based on preprogramed conditions.

FUNCTIONAL CAPABILITIES

Activation
MGC can perform required startup/activation routines on the DERs at the microgrid (e.g., balancing the ES system on startup).

Blackstart
MGC can blackstart the microgrid if the PCC is open and there is no power in the connected systems.

On-Grid Optimization
MGC can automatically dispatch of the DERs based on inputs such as weather forecast, price forecast, load forecast, etc. An in-program interface allows a user the ability to swap seamlessly between optimization types without having to stop or restart the microgrid.

Intentional Islanding
MGC can reduce power flow through the PCC to near-zero prior to issuing an open command to the PCC. After opening the device designated as the voltage/frequency regulating (V/f) device will begin supporting the microgrid's voltage and frequency at user-configured values. There must be no interruption of power to the load during islanding and the island must be established within 60 seconds of the command being sent. Islanding can be achieved either by password-protected user control in the MGC user interface or through remote network requests made by the control center to the MGC. Islanding must be maintained for a minimum of 7 days or to the point of exhaustion of the energy resources, whichever comes first.

Unintentional Islanding
MGC can recognize a non-requested opening of the PCC and automatically swap the V/f device to the proper mode to form the island without interruption of power to the load.

MGC can perform optimization of the DERs for multiple use cases with a primary objective to maintain the island indefinitely and cost efficiently.

Additional but non-required capabilities include:
- An in-program interface allows the user the ability to swap seamlessly between optimization types without having to stop or restart the microgrid.
- Capacity to configure an off-grid nominal voltage and frequency during operation without having to stop or restart the microgrid.

Intentional Resynchronization
MGC can modify nominal off-grid voltage and frequency to match that of the grid-side of the PCC for resynchronization in order to ensure phases and magnitudes become aligned properly for the PCC to reclose. There must be no loss of power to the load during resynchronization and it must occur within 60 seconds of the command being sent. Resynchronization can be achieved either by password-protected user control in the MGC user interface or through remote network requests made by the control center to the MGC., while should also be password controlled.

Unintentional Resynchronization
MGC can recognize a non-requested closing of the PCC and swap the V/f device to the proper mode for grid resynchronization without loss of power to the load.

Shutdown
MGC can completely shut down all DERs seamlessly with a single command. This function should be password controlled.

Optimization

MGC provides the ability to swap between optimization use cases without having to stop or restart the MGC. All optimizations are self-contained files with the same function definition to allow creation or modification of optimization routines without having to modify the MGC code. Optimization duration is nominally in 5-minute increments for a rolling 24-hour window but can dynamically adjust total duration based on minimum size of forecasted data required for the optimization.

OPTIMIZATION USE CASES

Economic Dispatch
MGC provides the means of optimizing dispatch of the DERs such that cost of operating the microgrid is minimized, while maintaining a rolling 72-hour window of feasible generation. Transmission grid price forecasting, natural gas fuel price, load forecasting, and solar forecasting, in addition to microgrid stability constraints, are all considered by the optimization routine.

PV Smoothing
MGC should optimize ES dispatch around PV to stay at or below a pre-defined maximum net ramp rate.

PV Firming
MGC should optimize ES dispatch around PV to target a pre-defined net output target of average power over some time interval. MGC should also be able to update the PV firming targets on a rolling 24-hour-ahead bases, based on solar forecasts.

Power Quality
MGC provides the means of optimizing dispatch of the DERs to produce a user-configurable net power factor, voltage, frequency, power factor, etc.

Off-grid Optimization
MGC provides the means of optimizing dispatch of the DERs utilizing Economic Dispatch, while maintaining higher stability constraints during off-grid operation.

Islanding Optimization
MGC provides the means of minimizing net power flow through the PCC so that transients are reduced when PCC is issued the open command.

Resynchronization Optimization
MGC provides the means of regulating voltage and frequency at resynchronization time such that microgrid voltage approaches that of the grid connection, while maintaining a frequency setpoint slightly higher than that of the grid in order to allow the phases to eventually line up so that the PCC can reclose.

Forecast Integration

MGC can read provided forecasts in a multitude of formats and interpret them internally so they can then be used for optimization purposes. MGC can utilize grid price, solar output, and load forecasts, as well as provides user-customizable default forecasts for situations where actual forecasts are absent. General use cases provide for 24-hours' worth of forecasting but can accept dynamically changing net durations and mismatched durations between multiple forecast sources.

End-Use Loads

MGC will have the ability to add in load control for grid- or customer- sited systems that are within the microgrid when islanded. This may include devices such as load control switches, thermostats, water heaters, or electric vehicle chargers. The MGC can poll these devices for current status information and send commands to reduce or increase usage depending on the scenario. Communications pathways may include vendor APIs or open standards such OpenADR 2.0 and CTA 2045.

Error Handling and Hardening

MGC implements multiple strategies to harden operations against unplanned situations such as: loss of communication to devices or forecasts, non-responsiveness of PCC operation requests, remote operation lockout timers, V/f device swapping, etc. Therefore, each critical pathway should have two methods of communication and control to add redundancy, e.g., the solar PV power output will be read from both the inverters and from the AMI system. The result is a controller that can handle real world application instead of just operating cleanly in an ideal scenario.

FORECASTS

Absence of Real-time Forecasts
MGC provides the ability for a user-defined forecast to be used for grid price, solar output, and load for situations where real-time forecasting may not be available.

Real-time Forecast Interruption
MGC handles disruption in real-time forecasts by taking the last applicable forecast and forecasting out from the current period if that time is contained within the last forecast. Once the current time exceeds that covered by the forecast, the default forecast is used.

Different Sized Forecasts
MGC handles situations where the forecast for one source (e.g., solar output) is of a different total duration than another forecast (e.g., load) by truncating the longer forecast and interpolating forecasted values at a timestep shared among all forecasts.

LOSS OF COMMUNICATION TO DEVICES

Watchdog
MGC utilizes a communications watchdog between the DERs and the MGC to determine connectivity/controllability of the DERs. When communications are interrupted, MGC automatically attempts to connect via a secondary communications pathway or removes the asset from its optimization planning. An alert is automatically sent to the users that communications have been lost. When communications are reestablished, MGC automatically adds the device back to the optimization strategy.

Uncontrolled Asset
When communications are lost to a device, MGC looks at redundant measurement values for that device (i.e., Ion meter) and utilizes those measurements in the optimization routine as DERs that are providing or absorbing power but do not accept setpoints.

V/f Device Communication Loss
When operating in an on-grid mode, if communication is lost to the designated V/f device, MGC automatically takes note of the next device capable of performing V/f duties in its prioritized list so generation mode change commands can be sent to the new device in the event of intentional or unintentional island.

When operating in an off-grid mode, loss of communication to the V/f device will cause MGC to send a V/f command to the next highest asset in its user-configurable list of potential V/f devices, thereby attempting to sustain the island stability even if the primary V/f device fails. Upon re-establishment of communication to the original V/f device, it is immediately told to go to P/Q and accept power setpoints instead of attempting to regulate voltage and frequency.

V/F DEVICE SWAPPING

Manual V/f Device Swapping
MGC provides the user a way to swap V/f designation for devices via its user interface for situations where a device may need to be disabled for maintenance or stability concerns, while maintaining uptime of the microgrid in an on-grid or off-grid scenario with no interruption in power delivered to the load.

Automatic V/f Device Swapping
MGC provides the ability to automatically swap V/f devices after a successful island or resynchronization after a configurable amount of time elapses following the transition. This allows for utilizing one device (e.g., energy storage) that might have a quicker response rate to picking up the V/f duties on an island to perform the actual islanding duties before swapping V/f duties to something that might be better suited to long term V/f control (e.g., generator). After resynchronization, MGC also provides the automatic capability of swapping back to the original V/f device for the next intentional or unintentional island.

REMOTE OPERATION PROTECTIONS

Because the requested islanding and resynchronization procedures can take an extended period due to both optimization and recloser requirements, a configurable lockout timer for remote operations is implemented to prevent multiple attempts of recloser operation before the previously request operation either completes or times out.

Manual Control

MGC provides the user the ability to manually control the activation, generation mode, and power setpoints of any device operating under its purview through a manual control pane.

Real-time Display

MGC provides the following measurements and status indicators for all devices located in a single window for maximum visibility of the entirety of the system.

DeviceID
A unique identifier for each device and forecasts under the purview of MGC.

Device Type
A generic device description (e.g., Energy Storage, Generator, PV, Forecast, etc.) for ease of identifying particular asset classes on the microgrid.

Activation Status
Comprised of two flags, Active and Inactive, gives the user insight as to the current status of the resource and its ability to accept commands.

V/F Device
A flag that denotes which device currently is understood by MGC to be the V/f device if such a mode is needed.

Modes
Current operating modes of the device (e.g., P/Q, V/F, etc.).

State of Charge
Display the state of charge of the energy storage.

Power
Both real and reactive power for all devices are displayed on a per-phase basis, in addition to the summation of the 3 phases.

Voltage
Voltage is displayed on a per-phase basis, in addition to the average of the 3 phases.

Current
Current is displayed on a per-phase basis, in addition to the average of the 3 phases.

Frequency
Frequency measured at the asset is displayed.

Connection Status
The health of the communication to the device is denoted by a grayed-out Device ID (no connection) or a black Device ID (currently communicating).

Use Case Requirements – Additional Details

MICROGRID USE CASES REQUIREMENTS	DESCRIPTION
Modes of Operation: Grid-connected, Islanded	
Grid-connected Use Cases	
Demand Management	
Method	
Peak reduction	The MGC dispatches active and reactive power flow at POI respecting upper and lower flow limits at POI and of the DERs. The upper and lower P and Q limits can be dynamically updated to cater for different operating conditions. To achieve peak reduction, the P and Q limits can be changed based on predefined schedules.
Load shaping	
Intelligent	Intelligent Loads (Smart Homes) reduction can be achieved by direct load control of customer systems such as HVAC, water heating, or EV chargers or by communicating to the systems via a vendor API or open communications protocol to adjust their operational state The MGC offers the capability to re-ceive the DR activation schedules and manage the activation of the DERs based on the schedule.
Scheduled	The scheduled load shaping uses predefined load reduction forecasts for each cluster to dynamically compute a load reduction schedule intended to achieve a specific load reduction profile: maximum load reduction, load reduction for a maximum duration, etc.
Rebound	The intelligent load shaving is extended to include the rebound effect when loads return to their normal operational parameters after being dispatched. The rebound is incorpo-rated into the intelligent planning algorithm so that the rebound effect can be mitigated by staggering the activation of load clusters.
DER dispatch (battery/generator) (P,Q power flow)	The MGC dispatches the battery and generators to maintain power flows at PCC within predefined limits or to achieve specific power flow targets at the PCC.
Reverse power flow potential	See section on "P, Q power flow" or on "peak reduction".
DER dispatch (battery/generator) (Economic dispatch)	The MG Optimizer derives a unit commitment and economic dispatch schedule to reach different economic objectives (energy cost, emissions, DER involvement, optimized islanding time).
Load shifting	Loads that can be activated are divided into clusters that can be dispatched to decrease or increase load for a predefined period. One example of load shifting could be turning water heaters or switching HVAC systems on and using the building and building systems as thermal storage. The MGC offers the capability of managing predefined load activation schedules.
Thermal storage	See section on load shifting.

Battery scheme - SOC management	The MG Optimizer supports reliability SOC constraints as part of the MG economic dispatch optimization.
Battery scheme - SOC envelope tracking	The MGC dispatches the available storage to main-tain its state of charge within a predefined min/max SOC schedule. The MGC can support business as usual and emergency schedules, based on an external signal.
Solar over-generation - curtailment	The MGC can monitor solar generation and provide alarms when generation is above certain thresholds. In certain cases (islanded operation and battery full) the MGC can curtail PV generation by providing set points to the PV control system (Smart inverters).
Power Quality	
Method	
PF control (@ PCC)	The MGC dispatches DER (battery, generator and PV) active and reactive power to achieve a power factor target at POI. The power factor can be provided either as an angle or as a power factor values and a direction (leading/lagging).
V control (@ PCC)	The MGC dispatched the DERs (battery, generator and PV) voltage to maintain a target voltage at POI.
f control	In connected mode mean the MGC receives signals from a central AGC, or that it implements a droop control whereby it increases/decreases active pow-er flow at POI based on measured frequency. The droop slope is a setting. In islanded mode the MGC dispatches the isochro-nous generator in V, f mode.
Flicker	The MGC monitor flicker values from meters and raise alarms if the values exceed predefined thresholds.
Harmonics	Same as for flicker. The MGC can monitor harmonics readings from meters and raise alarms if thresholds are exceeded.
Economic Dispatch	
Method	
Dispatch DER and loads based on price signal	MGC allows the microgrid to provide the ancillary market services to the grid through participation in the market. Spinning reserve, non-spinning reserve, and frequency regulation services can be managed for the microgrid depending on its DERs. This is part of the Operational Planning and Optimization module in the MEMS.
Requires load & PV predictions	The optimization framework can leverage the forecasts for generation and load to update DER set points in the microgrid over a configurable time horizon.
Requires fuel costs and efficiency per-formance information on system hardware	The MGC can dispatch DERs with the objective of minimizing the operation cost of the microgrid including fuel consumption cost, start-up/shutdown cost, operation and maintenance cost of generators, and BESS operating cost.
Renewable only (cost of carbon)	The MGC can dispatch DERs with the objective of minimizing Green-House Gas (GHG) emissions. The net emission cost of environmental pollutants (CO_2, SO_2, and NO) involved in the operation of the microgrid are assumed to be linear function of output power.
Demand charge reduction // Demand response	See Demand Management section for DR related functionality

Can be done day-by-day	The MGC can perform one shot day ahead optimization for creating a (setpoint) plan for the operator. The MEMS is utilizing a 'receding horizon optimization' method with configurable time interval as specified by the user to create the operator plan.
Works better with long-term predictions (load, weather)	See section on load & PV prediction.
Transactive control	Future
Dynamic load shaping based on customer comfort/price	See Demand Management section for DR related functionality.
TOU (time of use) and RTP (real-time pricing)	Future
Reliability	
Method	
Keep margin at all times in case of island condition	The MG Optimizer must incorporate reserve margins constraints in its optimization
Keep margin at all times in case of island condition (RT enforcement of margin limits based on external schedule)	The MGC operates the battery and generator within predefined state of charge and active power levels to have enough reserve margin in terms of power and energy to be capable of smoothly transitioning to islanded mode at any time.
Weather-based margin	The MG Optimizer must incorporate weather and load forecasts (hour ahead and day ahead) in reserve margin calculations.
Requires day-ahead weather predictions	
No margin for higher economics	

Islanded Use Cases (Intentional island planned)	
Seamless Islanding and Resynchronization	
Method	
Business-as-usual	The MGC brings the power flow at POI to zero (predefined low thresholds) by dispatching DERs. When the power flow is zero, the MGC sets one of the DERs to grid forming operating mode (V, f), changes the protection settings groups and open's the POI breaker. In the business as usual no loads are shed.
Looks normal to customer	
Island duration capability lowered	
Emergency	Like the business as usual islanding, except the MGC receives a signal indicating that non-critical loads should be shed to increase the islanding capability duration of the MG.

Load shedding for reliability	
Island duration capability raised	

Islanded Use Cases (UnIntentional island uplanned)	
Seamless Islanding and Resynchronization	
Method	
Business-as-usual	In case the PCC breaker opens, the MGC quickly sets one of the ESS to grid forming operating mode (V, f), changes the protection settings groups. If the no external signal is received, no loads are shed. When an external signal is received or the voltage on the grid side of the PCC breaker is back within statutory limits for a predefined period, the MGC automati-cally tries to resynchronize the MG with the grid by slipping the frequency of the MG and activates the synchro-check relay when authorized.
Looks normal to customer	
Island duration capability lowered	
Emergency	In case the PCC breaker opens, the MGC quickly sets one of the DERs to grid forming operating mode (V, f), changes the protection settings groups. If the MGC was is emergency mode prior to the islanding, non-critical loads are shed. When an external signal is received or the voltage on the grid side of the PCC breaker is back within statutory limits for a predefined period, the MGC automatically tries to resynchronize the MG with the grid and reconnects when authorized.
Load shedding for reliability	
Black start	In cases where voltage is lost within the MG, the MGC can automatically take the steps required to re-energize the microgrid. In this scenario the MGC first opens the PCC breaker and attempts to re-energize the MG using only the MG DERs. The black-start steps are MG dependent and will be defined together with SoCo.
Phase Balancing	
Method	
Load-shaping	The MGC monitors voltage measurements and raises alarms when phase imbalance is detected.
Worst-Case Testing	
Method	
High load	
Low load	

Other General Requirements
Electrical information regarding resistance and reactance of lines within system. (We would be able to calculate this if the minimum information regarding line separation distances, cable size, and lengths are provided.)
Limits on real and reactive power flow on the lines are also needed.
All load shedding should come with prioritization if economics are not available.

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