Bach Long Vy Microgrid

Control System Guide

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Document Revisions

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0.1	A. Zamani, H Bayat, H. Kruger		Oct. 26, 2020	Added black-start function and addressed review comments
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No table of figures entries found.

ACRONYMS AND ABBREVIATION

BESS	Battery Energy Storage System
BLV	Bach Long Vy
DER	Distributed Energy Resource
DG	Diesel Generator
HMI	Human Machine Interface
IED	Intelligent Electronic Device
MCS	Microgrid Control System
NRT	Near Real Time
PV	Photovoltaic
SCADA	Supervisory Control and Data Acquisition
SOC	State of Charge
VSG	Virtual Synchronous Generator
WTG	Wind Turbine Generator

1 OBJECTIVE AND SCOPE

This document describes key characteristics of the Bach Long Vy (BLV) microgrid and defines major requirements, assumptions, and criteria that were used to design and implement the BLV Microgrid Control System (MCS). When necessary, proper operating processes are also discussed in this document in a high-level manner.

The document should be treated as the microgrid control system operation guide for the BLV microgrid to help with appropriate operating process, based on the customer requirements. This document is not intended to describe microgrid operating procedures. However, where applicable, various operating modes and conditions of the BLV microgrid are described to help with the control system specifications.

2 INTRODUCTION

This section provides a general description of the BLV microgrid and its characteristics.

2.1 Project Overview

The Bach Long Vy (BLV) microgrid is an island microgrid system which includes the following major assts:

- One (1) 500kW Photovoltaic (PV) System, consisting of five (5) 100kW Inverters, and one PV plant controller.
- One (1) 500kW/1MWh Battery Energy Storage System (BESS)
- One (1) 1MW Wind Turbine (WT)
- Two (2) 1MW Diesel Generators (DGs)

The BLV microgrid is planned to facilitate the integration of clean energy resources while maintaining the system reliability level. Figure 1 shows a simplified Single-Line Diagram (SLD) of the BLV microgrid. As shown in this figure, the Distributed Energy Resources (DERs) are connected to the microgrid via a low-voltage switchgear and a 0.4kV/10kV interconnection transformers. The system is normally islanded, with no interconnection to a central grid.

All circuits, including two load feeders, are protected by GE F650 relays. Figure 2 shows a detailed SLD of the system.

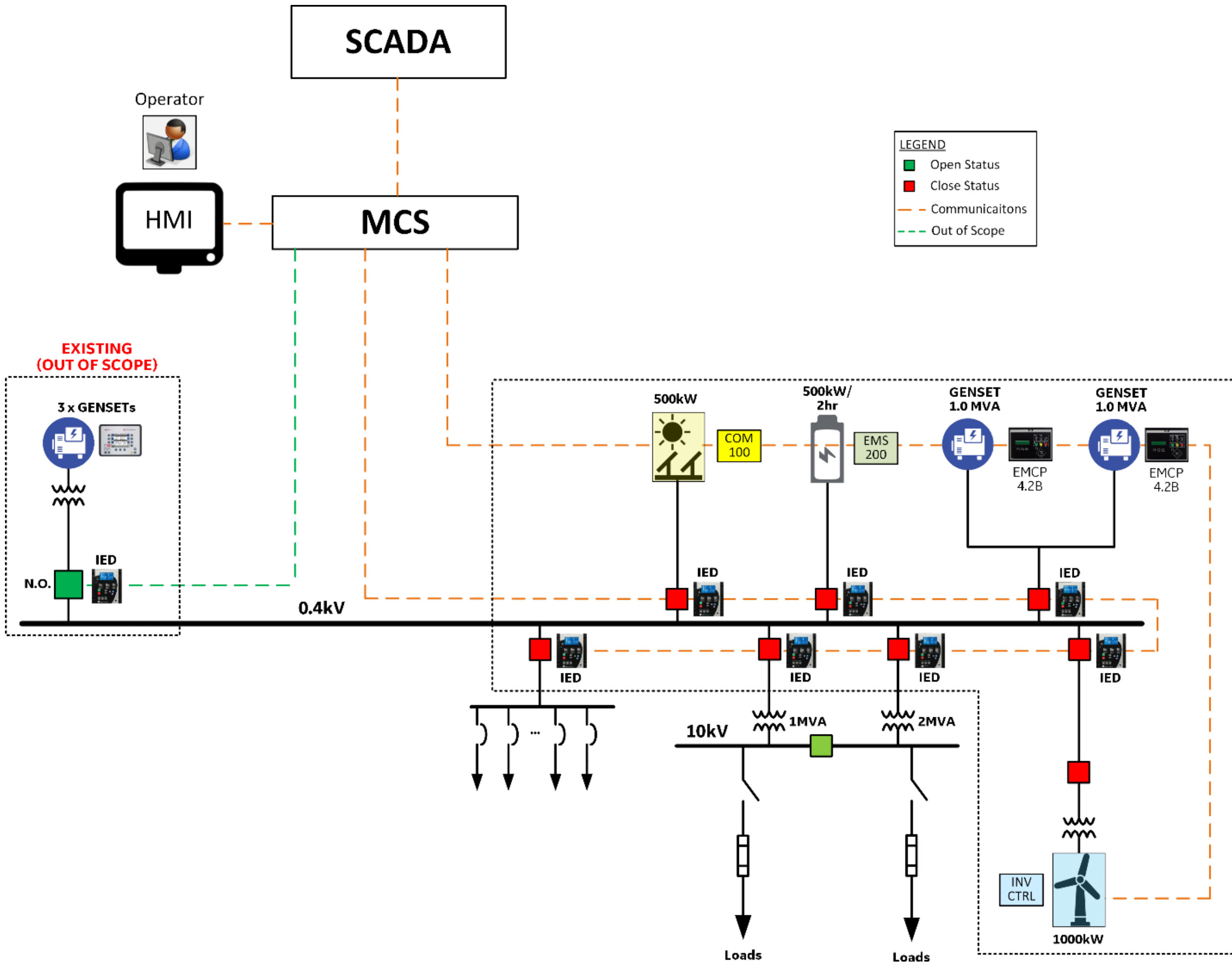

Figure 1- Simplified single-line diagram of the BLV microgrid

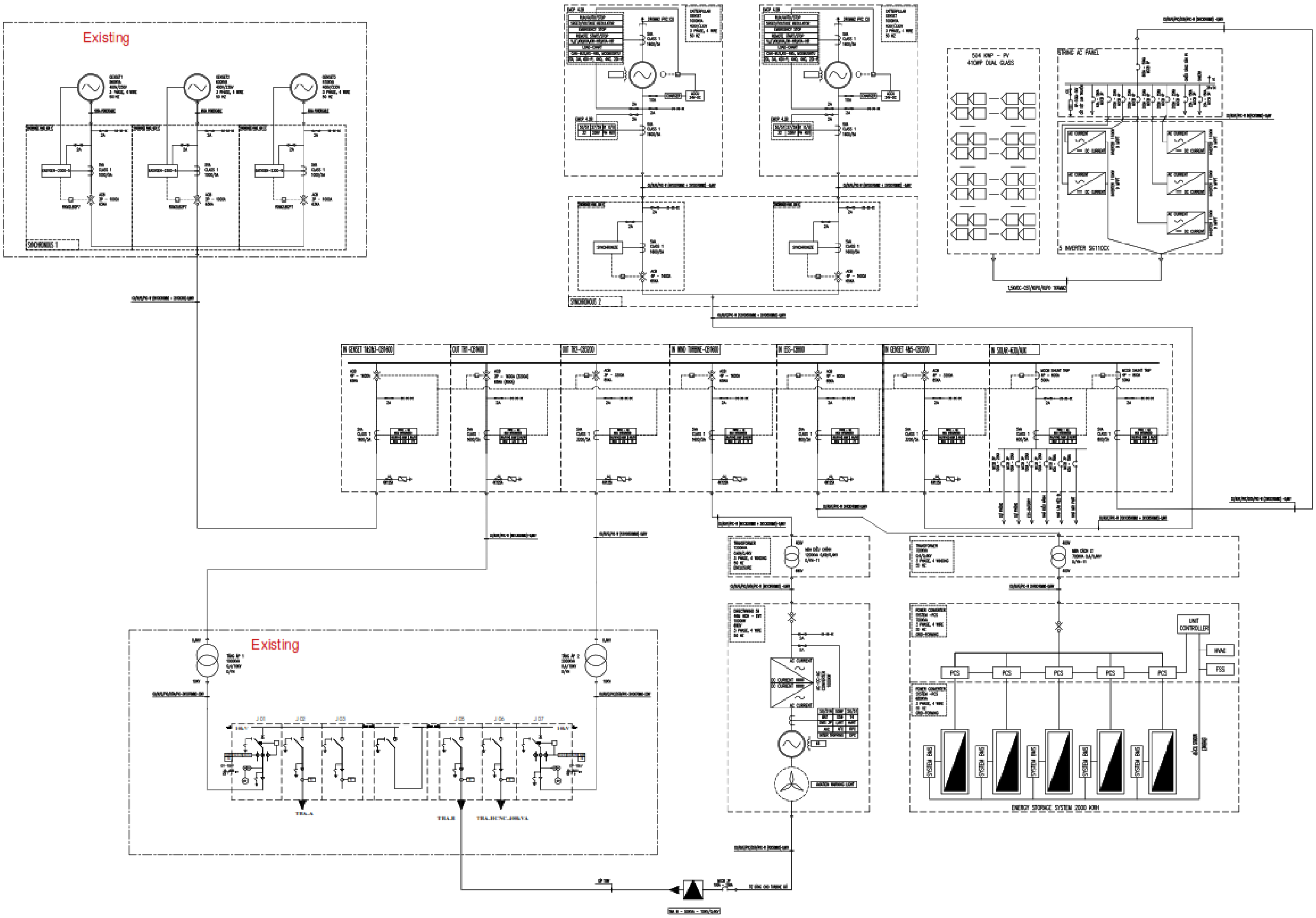

Figure 2- Detailed single-line diagram of the BLV microgrid

2.2 Project Phases

The BLV microgrid project is implemented in two phases as described below:

- *Phase 1:* This phase included deployment of 500kW PV system, 500kW BESS, and two 1-MW Diesel generators. The main objective of this phase is to replace existing three diesel generators with these DERs to reduce carbon footprint.
- *Phase 2:* In this phase, the BLV microgrid is expanded by addition of a 1-MW Wind Turbine Generator (WTG). The WTG is integrated into the MCS.

Figure 1 shows the major microgrid components that are involved in the microgrid. This document provides the operation guide for the MCS upon completion of phase 2.

2.3 Load Profile

As shown in Figure 1, the BLV microgrid has two load feeders protected by GE F650 relays. The relays will be setup to report load measurements to the MCS. All the loads are treated with equal priority, and no fast/slow load shedding is planned for the project.

Figure 3 shows the BLV microgrid load profile (maximum load) for Year 2020 (Phase 1). It can be observed that the peak load of the microgrid is 750kW, which is about 75% of each Diesel Generator (DG) nominal rating. It is also seen that the peak load occurs in the evening time.

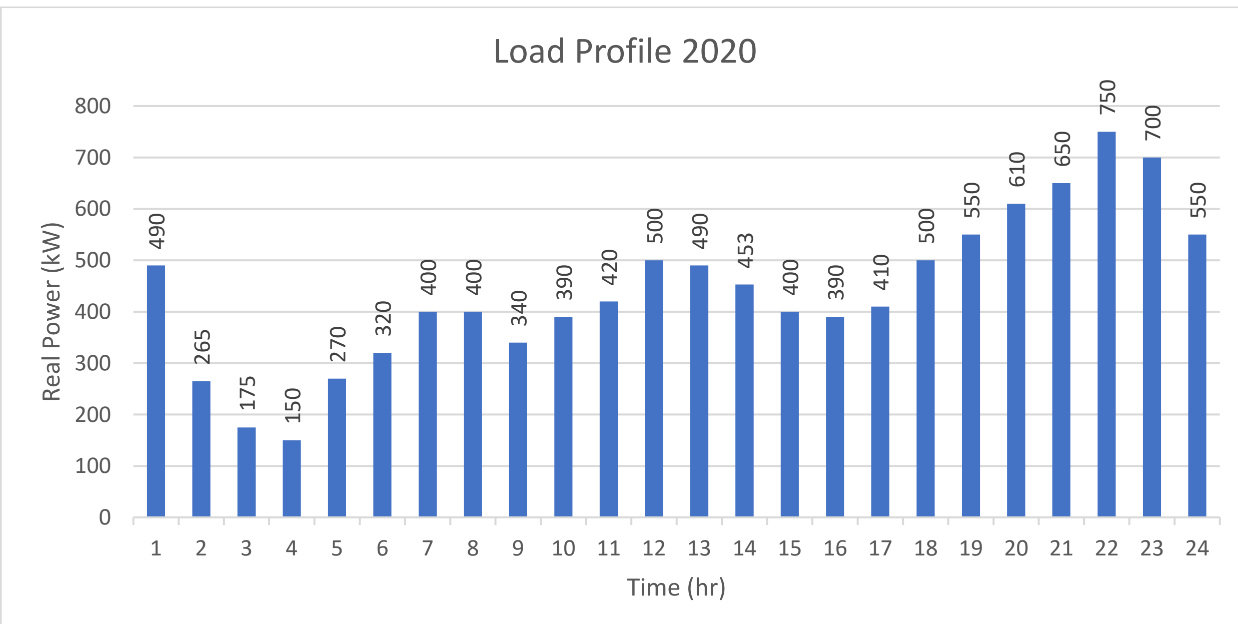

Figure 3- BLV microgrid load profile [Year 2020]

Considering the load growth, it is expected that the maximum load will reach 3MVA by 2025. The expected load profile for Year 2025 is shown in Figure 4.

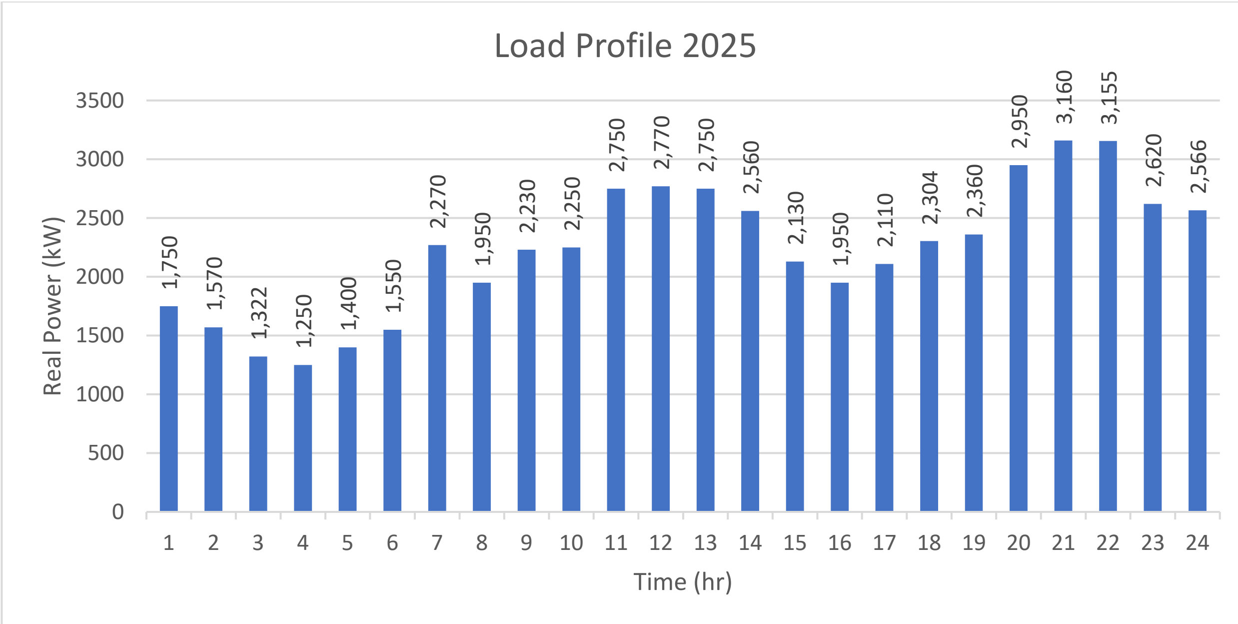

Figure 4- BLV microgrid maximum load profile [Year 2025]

2.4 Distributed Energy Resources

The two diesel generators and the BESS have grid forming capability. The MCS will use the available load data as well as near-real-time power measurements to implement a proper DER dispatch. The dispatch function's actions depend on the grid-forming DER, however, the objective remains maximizing the use of renewable energy resources. In the following subsections, the main control features of the DERs will be described:

2.4.1 Diesel Generator

To control the DG through a remote device (MCS), the "Engine Control Switch (ECS)" of the generator has to be set to AUTO position. Then, the engine can be started or stopped by the MCS to manage light- and high-load conditions. For example, the MCS will stop the second DG when the microgrid load is low and can be supplied by one DG in conjunction with PV, WTG, and the BESS. The MCS will also ensure that the DGs (one or both engines) are started when the load demand goes beyond a pre-defined value [1].

If only one DG is in service, the DG will be the grid-forming device. If both DGs are in service, the Gen2000 controller is expected to manage the load sharing and operating mode between them. In this case, both DGs can be in Droop mode (or one DG in Isochronous mode and the second one in Droop mode). Regardless, when one or two DGs are ON, they will operate as grid forming DERs and will regulate the voltage and frequency of the BLV system.

2.4.2 Battery Energy Storage System

The BESS supports the following operation functions [2]:

A- *Grid-Connection Operation function*: This function is divided into charging and discharging modes, which can be set via PC or the user interface. The specific on-grid charging and discharging modes are as follows:

1- Constant power charging/discharging (DC)
2- Constant power charging/discharging (AC)
3- Constant voltage charging/discharging
4- Constant current charging/discharging

In this *project*, the 'constant power charging/discharging (AC) mode' is used during the BESS grid-connection operation.

B- *Independent Inversion function (VF)*: This function is used for black-start purposes.

C- *Virtual Synchronous Generator (VSG) function*: This function is further divided into on-grid operation and off-grid operation. The BESS controller determines if there is another DER (DGs in the context of the BLV system) that regulates the voltage and frequency of the system and operates in VSG on-grid mode. Similarly, if there is no other DER that regulates the voltage and frequency of the system (loss of grid, i.e., DGs are off in the context of the BLV system), the BESS controller will switch to the VSG off-grid mode and regulates the voltage and frequency of the MG. In terms of control commands, the MCS sets the operation mode of the BESS to VSG and the controller of the BESS determines if it should operate in on-grid or off-grid mode, depending on the presence of the grid (see Section 2.4.2.2). If the black start is performed using the BESS as grid-forming DER, the MCS will put the BESS in VSG off-grid mode since the DGs are off. **Please note that for the current revision this mode is not activated on the BESS, but will be activated in the near future. The BESS is currently only capable of operating in grid-connected mode.**

D- Reactive power control: this function controls the reactive power output of the BESS system according to power factor or fixed ratio[1].

Figure 5 shows the block diagram of the operation functions supported by the BESS.

Based on the BESS operation functions, the operation modes of the BESS are as follows [2]:

2.4.2.1 Grid-Connected Mode

In the grid-connected mode, the BESS converter[2] can operate in charging or discharging state. As explained earlier, 'constant power charging/discharging (AC) mode' is selected during grid-connected mode to charge/discharge the BESS.

In the grid-connected mode, the BESS Converter can directly switch between charging state and discharging state without a need to a middle transition state.

[1] Reactive power management is out of the scope of this project.

[2] It is also referred to as the Power Conversion System (PCS).

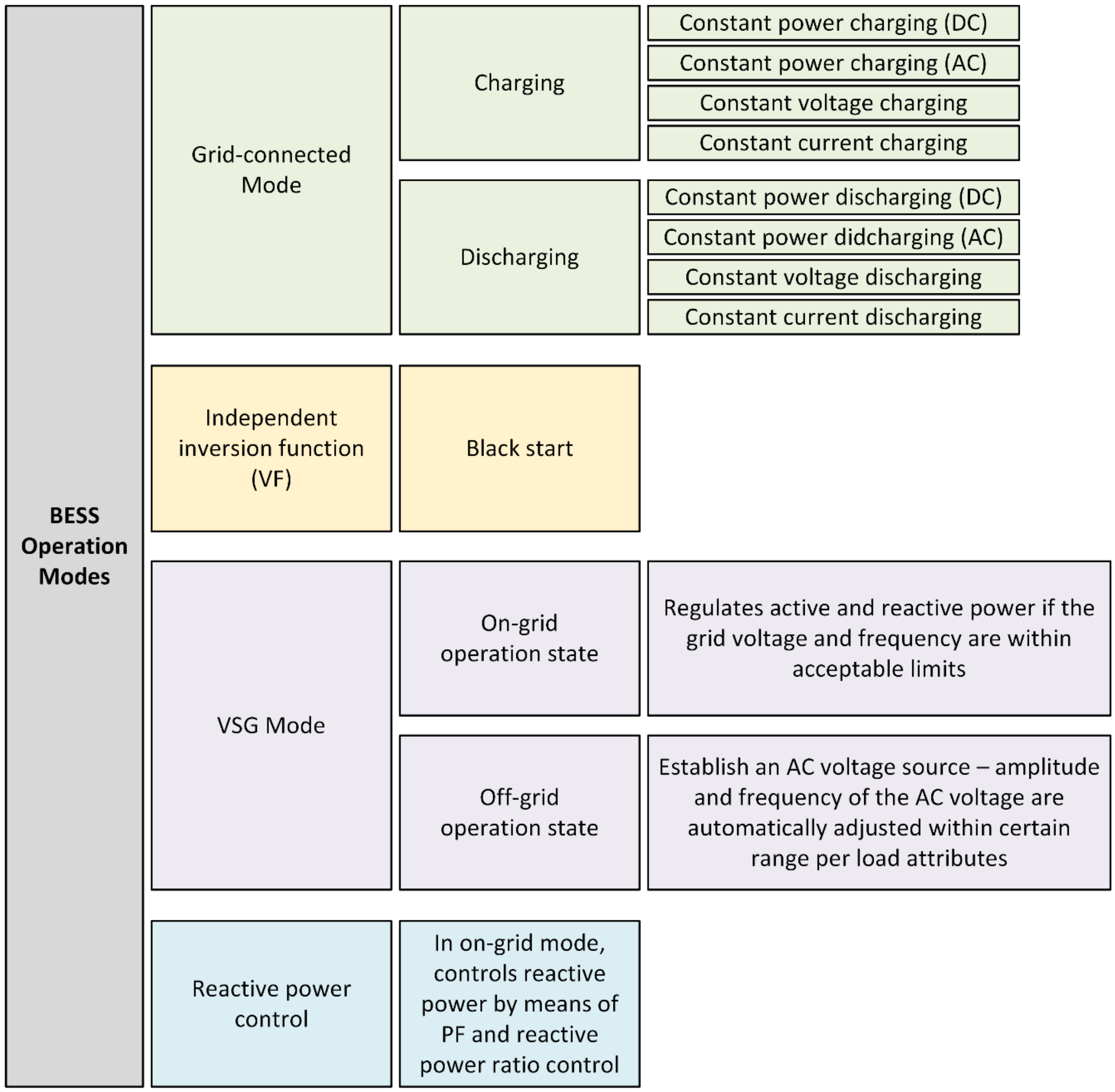

Figure 5- Operation functions of the BESS

2.4.2.2 VSG Mode

Virtual Synchronous Generator (VSG) control mode combines the converter control and synchronous generator control. The parameters that can be set in the VSG mode include (i) output voltage set value, (ii) output frequency set value, (iii) active power setting, (iv) reactive power setting, (v) frequency droop factor, and (vi) voltage droop factor. Depending on the system operating mode, the VSG mode has two operation states [2]:

- On-grid state: In this operating state, the converter controller automatically detects grid voltage signal and operates synchronous with the grid. The on-grid active and reactive power of the converter can be adjusted in this state. If the voltage and frequency of the grid are within the limit, the BESS will follow the active and reactive power setpoints. However, if the voltage and frequency of the grid are deviated from the nominal, the BESS will adjust its output active and reactive power in an effort to maintain the grid voltage and frequency. As a result, in this condition the BESS will not follow the active and reactive power setpoints.

- Off-grid state: In this operation state, the converter controller creates a voltage source within a specific frequency range to supply the loads. The off-grid magnitude and frequency of the no-load output voltage can be adjusted in this state.

Please note that for the current revision this mode is not activated on the BESS, but will be activated in the near future. The BESS is currently only capable of operating in grid-connected mode.

2.4.3 PV System

There are two control modes of the PV inverter which are utilized in this project: (i) Normal operation mode where the inverter delivers all power available from the PV panels to the BLV system and (ii) Power Curtail mode where the inverter delivers a defined amount of power to the grid which is smaller than the power yield of the PV panels [3]. The latter is used in situations where the load is low while the available PV power is high, and the BESS system is fully charged. This situation may not happen during a normal day where the load is usually high.

It is noted that no reactive power management is considered for the MCS in this project. Therefore, it is important to set proper default reactive power support for the PV that avoid grid forming DER overload.

2.4.4 Wind Turbine Generator

The wind turbine generator also has two operation modes: (i) Normal operation mode where the converter delivers all power available from the wind turbine to BLV grid and (ii) Power Curtail mode where the converter delivers a limited amount of power to the grid which is smaller than the power yield of the wind turbine [4].

The wind turbine generator has power rating of 1MW and is provided by EWT company. The MCS does not implement a reactive power management function. As a result, all reactive power requirement of the BLV grid is provided by the grid-forming DER (DG or BESS). However, the wind converter can be set to a proper default reactive power support to avoid overloading grid forming device.

2.5 Network Diagram

This section provides an overview of the MCS interfaces and connection points.

2.5.1 MCS Interface

The MCS directly interfaces with the following components in the BLV microgrid system:

- Microgrid Assets
  - PV system (COM100)
  - BESS (EMS100)
  - 2 x Diesel Generator (EMCP4.2)

- 8 x F650 (RMU)
- Wind turbine generator (DMS 3P Pro)
- Distribution SCADA

Figure 6 below shows the interfaces and the data follow between the MCS and abovementioned components. As indicated in this figure, the MCS is the Master to microgrid assets and communicates with them through standard protocols (DNP3, Modbus, IEC104, IEC61850). It also operates as Slave to the distribution SCADA and HMI.

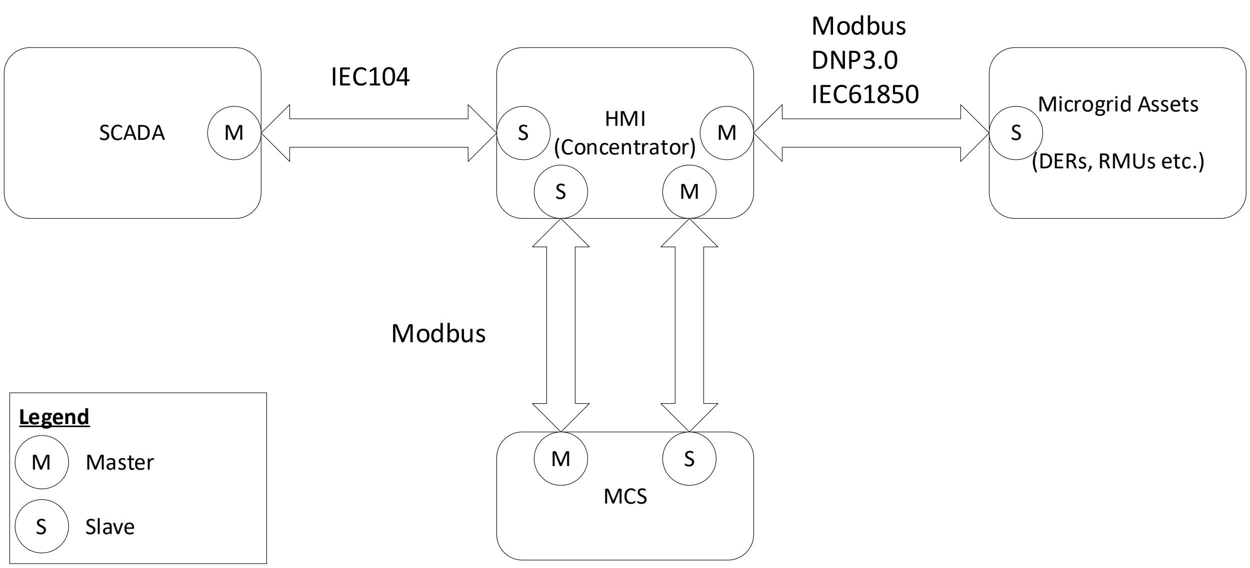

Figure 6- MCS interface architecture

2.5.2 Network Diagram

Figure 7 shows the communication diagram for the BLV microgrid.

2.6 System Operation Requirements

BLV microgrid is an island microgrid with no interconnection with a central grid. Currently, the island is energized with three diesel generators which will be replaced with the DERs listed in Section 2.1. In the new system, when any of the DGs (or both) is ON, the DG/DGs will regulate the voltage and frequency of the island according to the load sharing logic (Section 2.4.1).

Since the BESS does not support the transition from VSG off-grid to VSG on-grid or on-grid modes, the MCS always keeps a DG running. Otherwise, a black start was required every time that there was a need to start a DG.

Please note that for the current revision this mode is not activated on the BESS, but will be activated in the near future. The BESS is currently only capable of operating in grid-connected mode .

The BLV microgrid operates based on several automation schemes and intelligent controls such as:

- Black start
- Basic DER dispatch to enhance PV and wind contribution, given the asset constraints
- Regulation reserve management

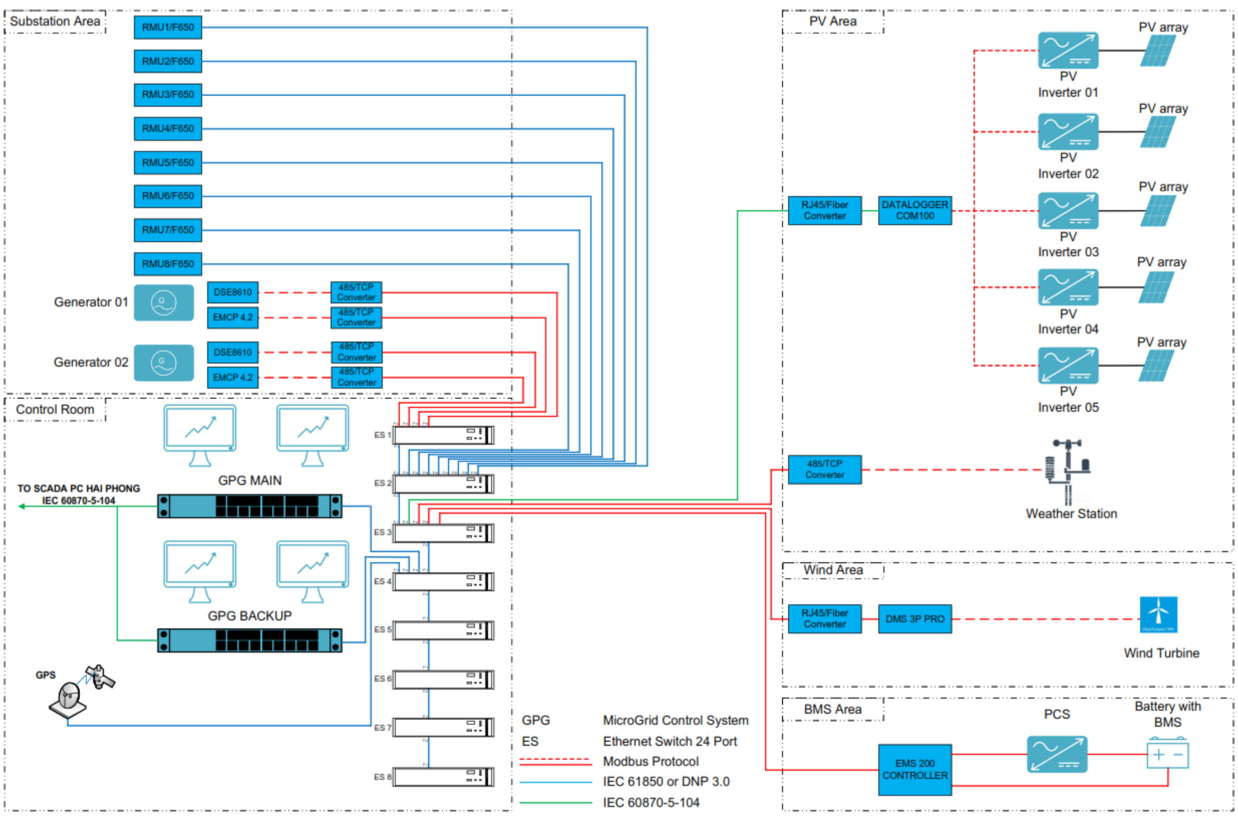

Figure 7- Communication diagram for the BLV microgrid

To achieve the abovementioned control functions, the BLV DERs shall support certain control functionalities, depending on their type. Some of these functions include:

- Grid-following capability
  - Constant power mode (with remotely adjustable P/Q setpoints)
- Grid-forming capability (voltage/frequency regulation or Power-frequency Droop)
- Adjustable no-load frequency/droop setpoints
- Black start capability
- On-the-fly control mode change (e.g., from the grid-following mode to the grid-forming mode)
- Remote communication capabilities

3 CONTROL SYSTEM REQUIREMENTS

This section outlines the design and operation of the control system and functions for the BLV microgrid. More specifically, the operation and development aspects of the control function/application will be discussed.

3.1 Control System Operating Modes

In general, the MCS will support two (2) operating modes that are described in the following subsections. The possible transitions between these two operating modes can be seen in Figure 8.

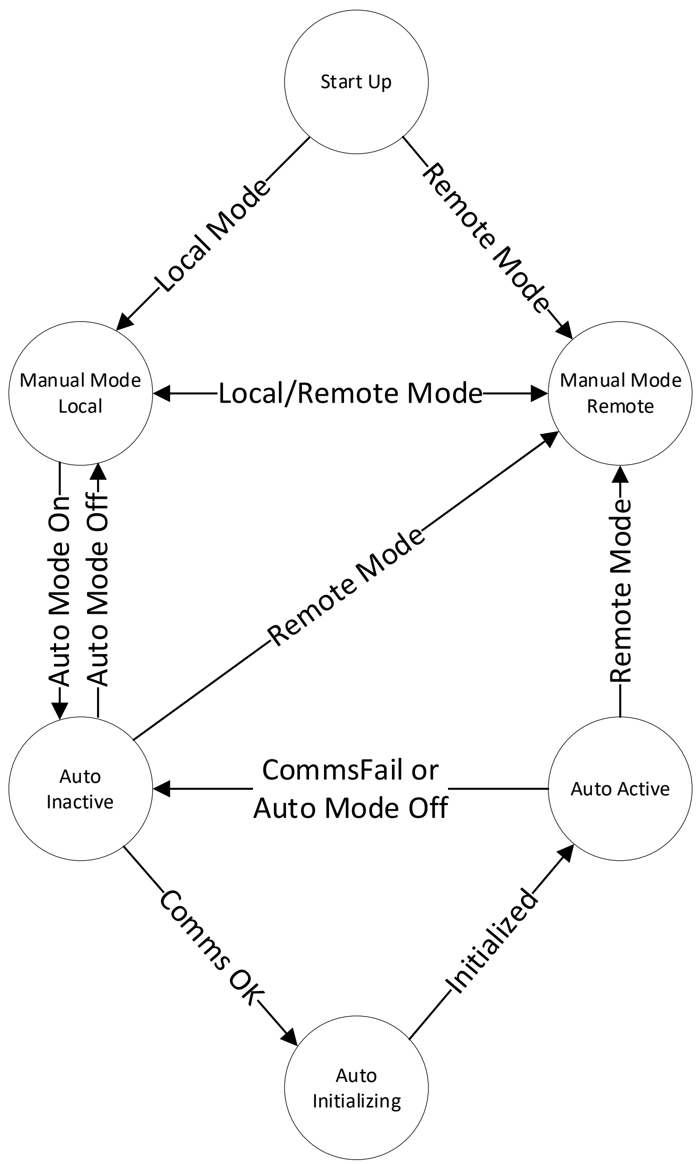

Figure 8- State Transitions for MCS Operating Modes

3.1.1 Manual Control Mode

When the MCS is operating in the Manual mode, the microgrid system is controlled by the operator. The Manual mode can further be categorized in two control groups:

- Local Control Mode: In this mode, the microgrid is controlled by an operator at the site level, i.e., via the local MCS' HMI.
- Remote Control Mode: In this mode, the microgrid is controlled by an operator at the control center level, i.e., via SCADA.

Various control functions will have the Enable/Disable feature. When the function is enabled, the related parameters (active power, reactive power, power factor, voltage settings, frequency droop settings, DER control mode, breaker status, etc.) can be adjusted by the operator either locally (HMI) or remotely (SCADA). When the function is disabled, the operator cannot control/adjust the parameters.

3.1.2 Automatic Control Mode

When the MCS is operating in the Automatic mode, the MCS calculates and adjusts the controllable system parameters fully automatically (active power, DER control mode, breaker status, and etc.). In other words, in this mode, the control is done with limited operator intervention. Auto Mode will only be enabled if the MCS is in Local Control Mode. Once Auto Mode is enabled, the MCS will go through an Initialization process that takes about 5 seconds. Once the initialization is complete and the communication status is good, the Auto mode becomes active, and the Dispatch function is called. Auto mode will become inactive again if a communication failure is detected for longer than 30 seconds. If this happens, the initialization process will have to be executed again once communication is restored. If the Remote-Control Mode is enabled if the MCS is in Auto mode, then the MCS will immediately make stop the various functions and switch to Manual Control (Remote Control Mode). If the Local Control mode is enabled again, the MCS will reinitialize the Auto mode.

3.2 Data-Flow Diagram

Figure 9 shows a high-level data flow diagram for the BLV microgrid, which includes the main components involved in various control functions. The processes and exchanged information will be described for each control function in the following sub-sections.

3.3 Near-Real-Time DER Dispatch

3.3.1 Brief Description and Objectives

The Near-Real-Time (NRT) DER Dispatch function will adjust DER real power output setpoints to maximize the use of renewable energy resources (i.e. PV and Wind in this case), manage the BESS State of Charge (SOC) and maintain a minimum amount of load on the Diesel Generators while supplying the microgrid loads.

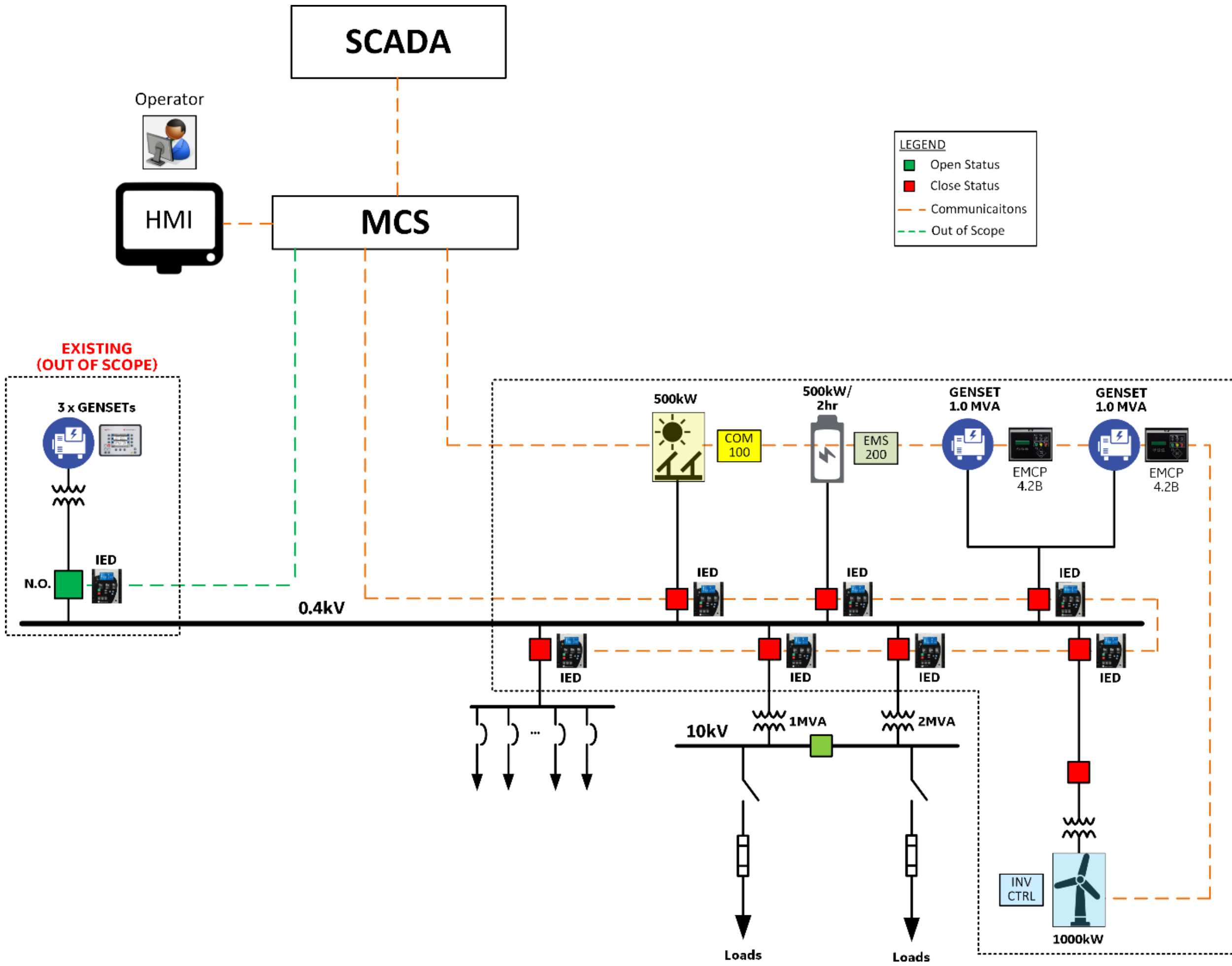

Figure 9- High-level data flow diagram

The main objective of the dispatch function is to:

- Properly charge/discharge the BESS, using near-real-time load and generation measurements (without load/generation forecast data) to maximize the use of renewable energy resources;
- Regulate the BESS power output during high- and low-load conditions to manage its State of Charge (SOC) while reducing the use of fossil-fuel-based generation.
- Maintain a minimum amount of load on the DG for fuel efficiency and reliability purposes.
- Curtail PV and Wind generation, only if it is needed, as the last option to keep load-generation balance.
- Initiate a blackstart if needed and/or dispatching is no longer possible (e.g. no dispatchable resources are connected).

The function is executed periodically in auto mode with the cycle time adjustable from a minimum of 2 minutes (default setting) up to a maximum of 10 minutes. On each cycle the function will first determine if the system is dispatchable which requires at least one grid-forming DER (DG or BESS), one connected load, and a minimum load of at least 10kW. If the system is not dispatchable, a blackstart will be initiated.

The dispatch function also has a feature to automatically connect and start the PV, Wind, BESS or a load that is not connected at the time of execution. This feature can be enabled / disabled with the relevant setting on the HMI. If the feature is enabled, the start sequence for the PV and Wind will be initiated with an initial active power limit of 0kW. The active power limit will be raised in subsequent cycles by the dispatch function if permitted by the state of the microgrid. Similarly, the BESS will be started in on-grid constant AC power mode with an active power setpoint of 0kW. The loads will only be connected if the required Regulation Reserve will be kept after connection. The Regulation Reserve after connection of the load is evaluated using a snapshot taken of the active power measured when the load was last connected.

The dispatch function operates in two modes of operation:

- Mode 1: The BESS is the grid-forming device and operating in the VSG Off-grid mode, while the Diesel Generation is not running. The curtailment setpoints on the Wind and PV may be adjusted as needed to maximize the renewables in maintaining the BESS SOC and Regulation Reserve. If the function can no longer maintain the Regulation Reserve and/or the SOC is outside of the allowable range, the Regulation Reserve Management function will assume control and may initiate a blackstart in the attempt to start a DG as it is not possible to seamlessly transition from VSG Off-grid mode to VSG On-grid mode. The BESS controller does not support charging while in off-grid mode and this is considered by the microgrid controller. As a result, a static downwards regulation reserve of 50kW is maintained, while the upwards regulation reserve is still managed according to the setpoint provided by the operator. **Please note that since the BESS currently does not support VSG mode, Mode 1 has been disabled on the controller until the function is activated. Please contact GE for support.**
- Mode 2: The Diesel Generators (DG) are the grid-forming devices, and the BESS will predominantly be operated in on-grid constant AC power mode if available, while switching to VSG On-grid mode when needed to provide additional Regulation Reserve (performed by the Regulation Reserve Management function). The Wind and PV curtailment setpoints will be adjusted as required to maximize the renewables, maintain the BESS SOC, maintain a minimum load on the DGs, and maintain the required Regulation Reserve. If the load on the DG falls below the minimum level (adjustable by the operator), the function will attempt to charge BESS first (if possible) before applying curtailment if needed. If the load on the DG goes above some maximum level (adjustable by the operator), the function will first attempt to remove any curtailment that has been applied to reduce the load on the DG. If no curtailment is applied then the function will attempt to reduce the load by adjusting the active power setpoint of the BESS (either down to full charge or to a minimum discharge level, depending on the BESS SOC and Charge Cycle). If the load of the DG is between the minimum and maximum levels, and there is still some curtailment applied, the function may attempt to remove small amounts of the curtailment if it is possible to absorb that generation with the BESS by lowering the active power setpoint of the BESS. The function will also start / stop a second DG to ensure the microgrid's upwards Regulation Reserve margin is kept. If the BESS is offline, the second DG will be started once the Regulation Reserve is within 100kW of the required margin. If the BESS is online, the second DG will only be started if the Regulation Reserve is within 100kW of the required margin and the BESS cannot be used to restore the

reserve (e.g., BESS already at maximum generation allowed) or if the BESS SOC is low and the loss of generation will lead to the Regulation Reserve to be within 100kW of the required margin. Once the second DG is started, it will only be stopped once the Regulation Reserve will be kept within 200kW of the required reserve after stopping the second DG. This is done to create a deadband of about 100kW to ensure that the DG is not started / stopped repeatedly. **Please note that VSG mode is currently not supported by the BESS and it will only be operated in grid-connected mode until VSG is activated.**

3.3.2 Sequence Diagram

Figure 10 shows the sequence diagram for the DER dispatch function. The details of the solid color filled process rectangles in the flowchart are elaborated in the Appendices section.

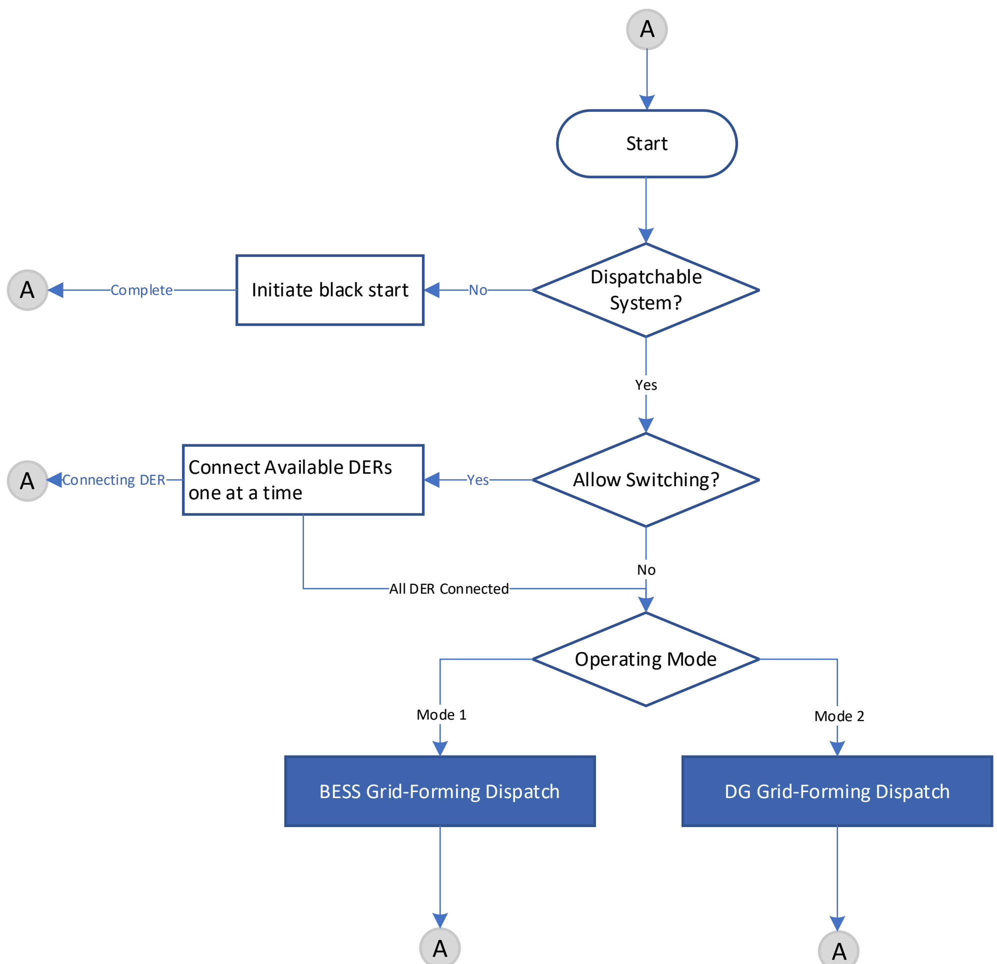

Figure 10- Basic DER dispatch flowchart

3.4 Regulation Reserve Management

3.4.1 Brief Description and Objectives

The frequency of the microgrid is controlled by the grid-forming DER (diesel or BESS). The frequency regulating mechanisms of the grid-forming DER must react to short-term frequency deviations to maintain a stable microgrid. Sufficient regulating reserve is needed and is maintained by the MCS for the grid-forming DER to respond. The Regulation Reserve Management function is activated when the reserve decreases below a minimum level (adjustable by the operator) and blocks the dispatch function until the function restores the Regulation Reserve required.

In Mode 1, the BESS is the grid-forming DER and the function will apply or remove curtailment to the renewable sources (PV and Wind) as needed to maintain sufficient regulating reserve on the BESS. The BESS controller does not support charging the batteries when in off-grid mode and this is considered by the microgrid controller. As a result, a static downwards regulation reserve of 50kW is maintained, while the upwards regulation reserve is still managed according to the setpoint provided by the operator.

When operating in Mode 2 the DG is the grid-forming DER with the BESS operating in on-grid constant power (AC) mode. If the reserve margin of the diesel generators is insufficient, the MCS will change the mode of the BESS to the VSG On-grid mode to provide additional regulating reserve until the reserve can be restored by means of curtailment, adjusting the BESS active power setpoint, and/or starting another Diesel Generator. **Please note that the VSG on-grid mode is not supported currently by the BESS and it will only be operated in on-grid constant Power (AC) mode until activated on the BESS controller.**

3.4.2 Sequence Diagram

The flowchart for the Regulation Reserve Management function is shown in Figure 11. The details of the solid color filled process rectangles in the flowchart are elaborated in the Appendices section. In this flowchart, RR_D and RR_U denote the actual downward and upward regulating reserve capacity, respectively. The $RR_{D\text{-}REQ}$ and $RR_{U\text{-}REQ}$ denote the required downward and upward regulating reserve capacity that the MCS should maintain and is adjustable by the operator with a minimum of 100kW and a maximum of 200kW (default). The regulating reserve capacity is calculated depending on the following system operating status:

- Mode 1 (The BESS is the grid-forming device and provides the regulating reserve)
- Mode 2 (The DG is the grid-forming device and the regulating reserve is calculated with the goal of operating the BESS in the on-grid constant AC power mode and maintaining the required regulating reserve with the DG)

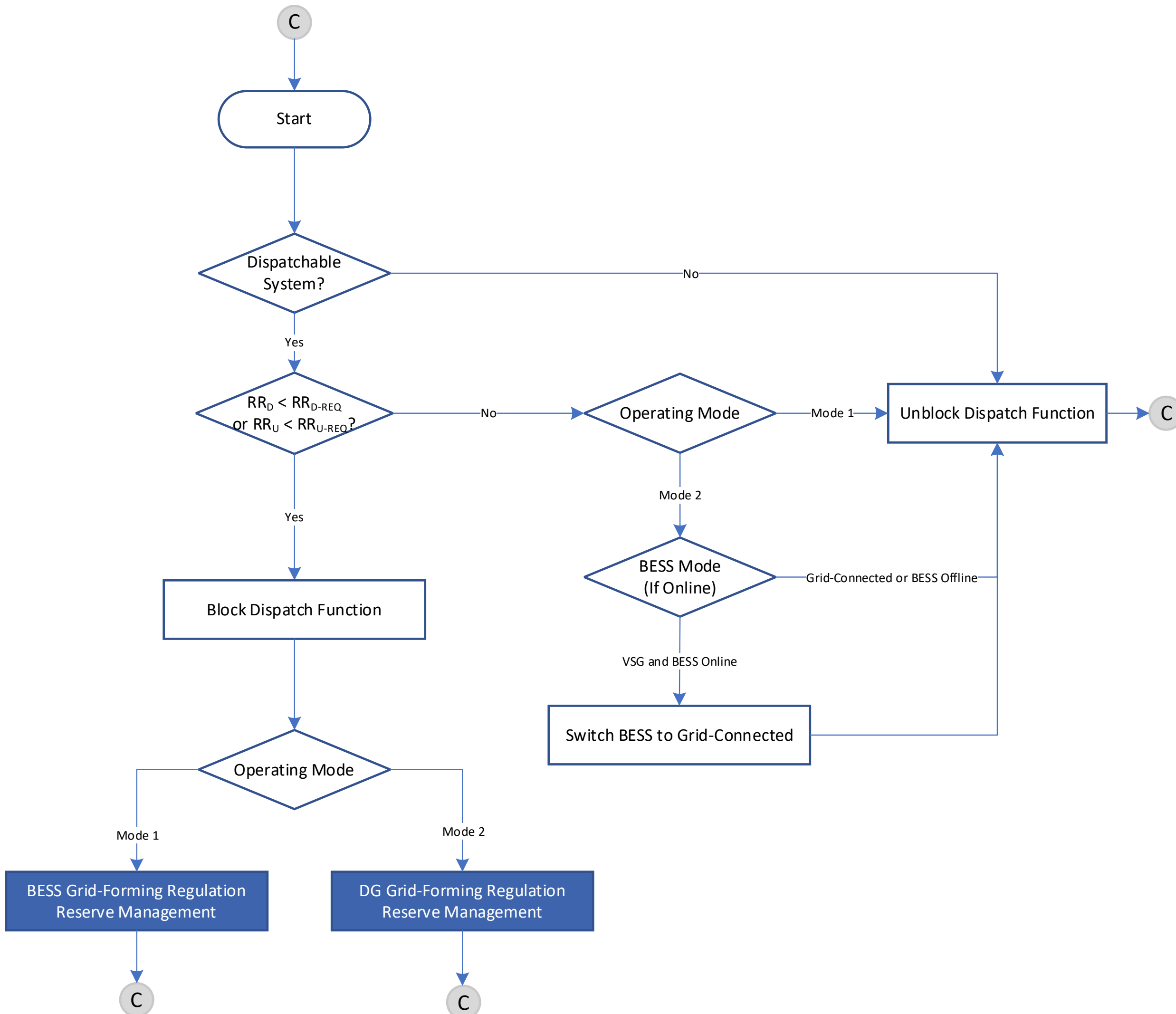

Figure 11- Basic regulation reserve management flowchart

3.5 Black Start

3.5.1 Brief Description and Objectives

In cases of a system black out, this control function will perform a sequence of (switching) actions to energize the microgrid (either automatically or via operator request). This assumes that one of the DERs (at a minimum) has black start capability.

The Blackstart function can be initiated by the Dispatch algorithm for two reasons:

- A non-dispatchable system is detected: At least one grid-forming DER and one load needs to be connected and a minimum of 10kW load is measured to be considered a dispatchable system. Otherwise, a Blackstart will be initiated.

- The Dispatch function is executed under Mode 1 (i.e., the BESS is the grid-forming DER), but the SOC of the BESS is below the minimum and/or the BESS is approaching its maximum active power rating.

The Blackstart algorithm can be executed in two modes:

- Mode 1: A Blackstart will be performed with the BESS as the grid-forming DER only if a Blackstart is possible (see detailed MCS sequence in the appendix for the relevant criteria). The MCS will start the BESS in VSG off-grid mode. If a successful start is detected, the MCS will connect the smaller of the two loads (based on the snapshot taken from the last time the load was connected when the microgrid was dispatchable). If the MCS fails to connect the smaller load, it will try to connect the larger load (if available). Once the first load is connected, the MCS will proceed to connect the PV and the Wind (if available) and set their curtailment setpoints to the appropriate value to maintain the minimum required downwards regulating reserve. Finally, the MCS will connect the larger load (if available) if the upwards regulating reserve will be maintained upon connection. **Please note that Mode 1 is currently disabled because the BESS does not support VSG Off-grid mode now. Mode 1 can be enabled as soon as the VSG mode is activated on the BESS controller. Please contact GE for assistance.**
- Mode 2: A Blackstart will be performed with the DG as the grid-forming DER only if a Blackstart is possible (see detailed MCS sequence in the appendix for the relevant criteria). The MCS will first connect the DG with the least number of operating hours. If the DG fails to start, the MCS will attempt to start the other DG (if available). The MCS will then proceed to start the BESS (if available) in VSG On-grid mode with an active power setpoint of 0kW. **Please note that VSG mode is not currently supported by the BESS controller and the BESS will only be operated in on-grid mode for now.** If required (depending on the load snapshots), the MCS will then proceed to start the other DG (if available and not already started). Once complete, the MCS will connect the smaller load, PV and Wind and the larger load in the same way as in Mode 1. As a final step, the MCS will adjust the BESS active power setpoint to ensure that the required downwards regulating reserve will be kept before switching the BESS to on-grid constant power (AC) mode.

The operator can select the Blackstart Priority (i.e. Mode 1 vs Mode 2) and can also enable/disable the MCS to switch modes automatically if needed. **Please note Mode 1 is currently disabled until the VSG off-grid is activated on the BESS controller. Please contact GE for assistance.**

3.5.2 Sequence Diagram

The flowchart for the black-start control function is shown in Figure 12. The details of the solid color filled process rectangles in the flowchart are elaborated in the Appendices section.

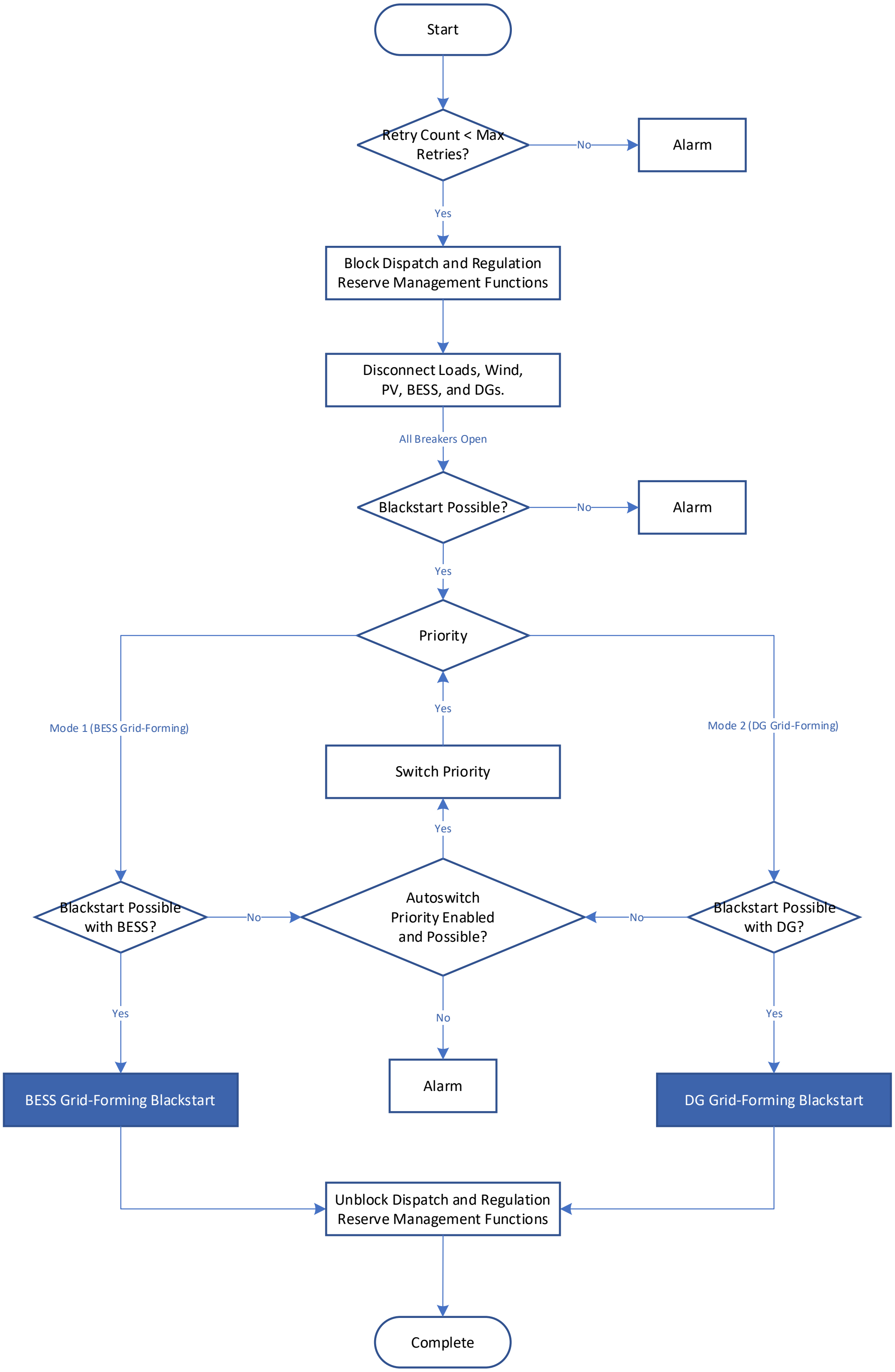

Figure 12- Black-start control flowchart

3.6 Control Functions

This section presents the sequence and actions needed to connect and disconnect the DERs to and from the BLV network.

3.6.1 Curtailment Function

The MCS has a curtailment function that manages the active power contribution of the PV and Wind. The operator can specify which resource should be curtailed first (i.e. PV or Wind) and the function will always attempt to curtail that resource first and will also then remove curtailment from that resource last (i.e. Apply first / Remove last priority).

The function has three main modes of operation:

- Apply: The Dispatch and Regulation Reserve Management functions can call the curtailment function with an apply command and an amount of active power to be curtailed. The curtailment function will then apply this amount of curtailment in two steps according to the priority specified by the operator. In the first step, the function will calculate how much of this amount can be curtailed on the resource specified by the priority setting. In the second step, it will calculate the remaining amount that needs to be applied and apply that to the other resource if possible. It should be noted that the apply command of the curtailment function will always result in reduction or the DER to the setpoint provided by to the dispatch function.

- Remove: The Dispatch and Regulation Reserve Management functions can call the curtailment function with a remove command and an amount of active power to be restored. The curtailment function will then remove this amount of curtailment in two steps according to the priority specified by the operator. In the first step, the function will calculate how much of this amount can be removed from the resource specified by the priority setting. In this case though, whatever resource has been specified by the priority will be restored last (e.g. If PV is given priority for curtailment, the function will apply curtailment first to PV and attempt to restore it last). In the second step, it will calculate the remaining amount that needs to be removed and apply that to the other resource if possible. It should be noted that the remove command of the curtailment function is not guaranteed to increase the output of the DER to the value specified in the setpoint of the function. The amount of power that will be restored after executing curtailment remove command depends on the amount of power available from the PV panels and wind turbine.

- Adjust: The adjust mode of the curtailment function is executed periodically on the same schedule as the Regulation Reserve Management function (30 seconds default setting). In this mode, the function always ensures that the curtailment setpoint of each resource is a maximum of 100kW above the current generation. This is done to prevent a sudden increase in generation (e.g., clouds clearing on the PV) from collapsing the microgrid.

The function also determines from the current setpoints whether there is still curtailment that can be applied and/or if curtailment is currently applied. Both flags are used by the Dispatch and Regulation Reserve Management functions.

3.6.2 BESS SOC Management Function

The BESS SOC Management function is called by the Dispatch and Regulation Reserve Management functions to determine the appropriate active power setpoint to issue to the BESS controller, based on the current system conditions and charge cycle of the BESS.

The BESS can operate in three distinct charge cycles with different objectives:

- Charge Only: In the Charge only cycle, a maximum active power setpoint of -45kW will be maintained on the BESS to charge the BESS. Higher charging rates up to the rated active power will be permitted as well if the microgrid conditions permit it (e.g. high renewable generation available, or low load on the DG). Discharging is not allowed in the Charge Only cycle. The BESS is automatically switched to the Charge-Only cycle once the $SOC_{MIN-MCS}$ level (adjustable by the operator) has been reached.
- Charge / Discharge: In the Charge / Discharge cycle, the active power setpoint will be changed to whatever is required by the microgrid to ensure the minimum load on the DG and to maximize renewable generation. The BESS is automatically switched to the Charge / Discharge cycle once the $SOC_{MAX-MCS}$ level has been reached and the BESS is in Charge Only mode.
- Discharge Only (Optional): In the Discharge only cycle, a minimum active power setpoint of 45kW will be maintained on the BESS to discharge the BESS. Higher discharge rates up to the rated active power will be permitted as well if the microgrid conditions permit it (e.g. all curtailment removed and high load on the DG). Charging is not allowed in the Discharge Only cycle. The BESS is only switched to the Discharge Only mode if the feature is enabled by the operator, the BESS is in the Charge/Discharge cycle and the BESS SOC has been above the midpoint between the $SOC_{MIN-MCS}$ and $SOC_{MAX-MCS}$ for a period exceeding t_{PER_DIS} (all adjustable by the operator).

3.6.3 BESS Unloading Function

Once the BESS approaches the $SOC_{MIN-MCS}$ or $SOC_{MAX-MCS}$ values, the MCS needs to unload the BESS before switching the cycle (e.g. Discharging to Charging). The MCS has an algorithm that unloads the BESS and at the same time utilizes the curtailment of the renewables to ensure that the regulating reserves are maintained.

If the BESS is operating as a load, the MCS will increase the BESS active power setpoint and apply curtailment to the renewables in 100kW steps every 15 seconds once the Unload function is called until the BESS active power setpoint is 0. The BESS SOC Management function will then specify the new setpoint and switch the BESS to the appropriate cycle.

If the BESS is operating as a generator, the MCS will decrease the BESS active power setpoint and remove curtailment (if available) from the renewables in 100kW steps every 15 seconds once the Unload function is called until the BESS active power setpoint is 0. The BESS SOC Management function will then specify the new setpoint and switch the BESS to the appropriate cycle.

3.7 Generic DER Models

The generic model for the DERs (DG, BESS, PV, and Wind) is shown in Figure 13. Each DER model implements similar Start and Stop Sequences and a Circuit Breaker Open and Close Sequence. Each DER model also has the same outputs as shown below as a minimum. These common features are presented in this section, while the DER-specific features are presented in the next section.

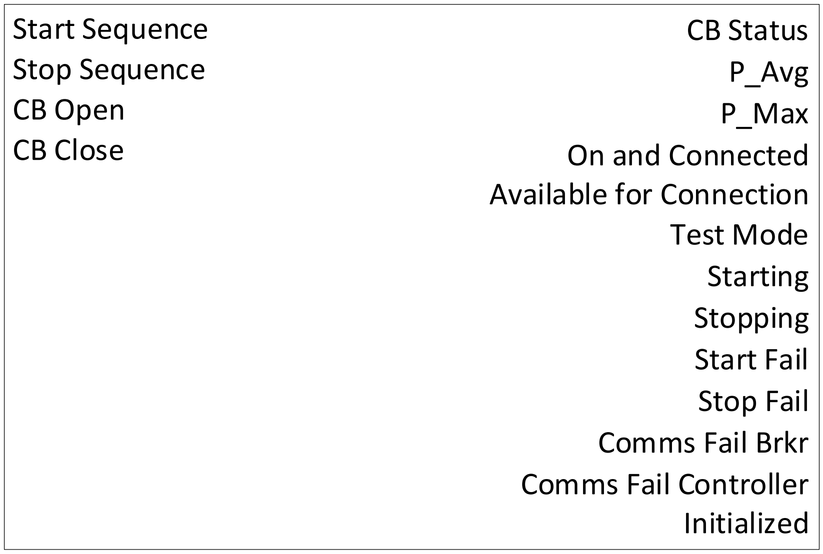

Figure 13- Generic DER Model

3.7.1 Start/Stop Sequence

A generic Start/Stop sequence is implemented for each DER and can be seen in Figure 14 and Figure 15 respectively. Once a Start command has been issued, the DER switches to the Starting state and starts the timer for the start sequence. If the DER indication does not show that the DER is stopped, then the Stop command is sent first. Once the DER is confirmed as stopped, the Point of Interconnection (POI) breaker is closed (if not already closed). As soon as the POI circuit breaker is confirmed to be closed, the Start command is sent to the DER. If the DER is detected as being on and connected, the Start sequence finishes successfully. If the timer expires before this happens, a Start Fail event is declared, the stop command is sent and the DER is made unavailable for 10 minutes.

When a Stop command has been issued, the DER switches to the Stopping state and starts the timer for the Stop sequence. If the DER indication still shows on and connected after the timer expires, a Stop Fail event is declared.

The amount of time to wait to declare a Start or Stop Fail event is adjustable by the operator.

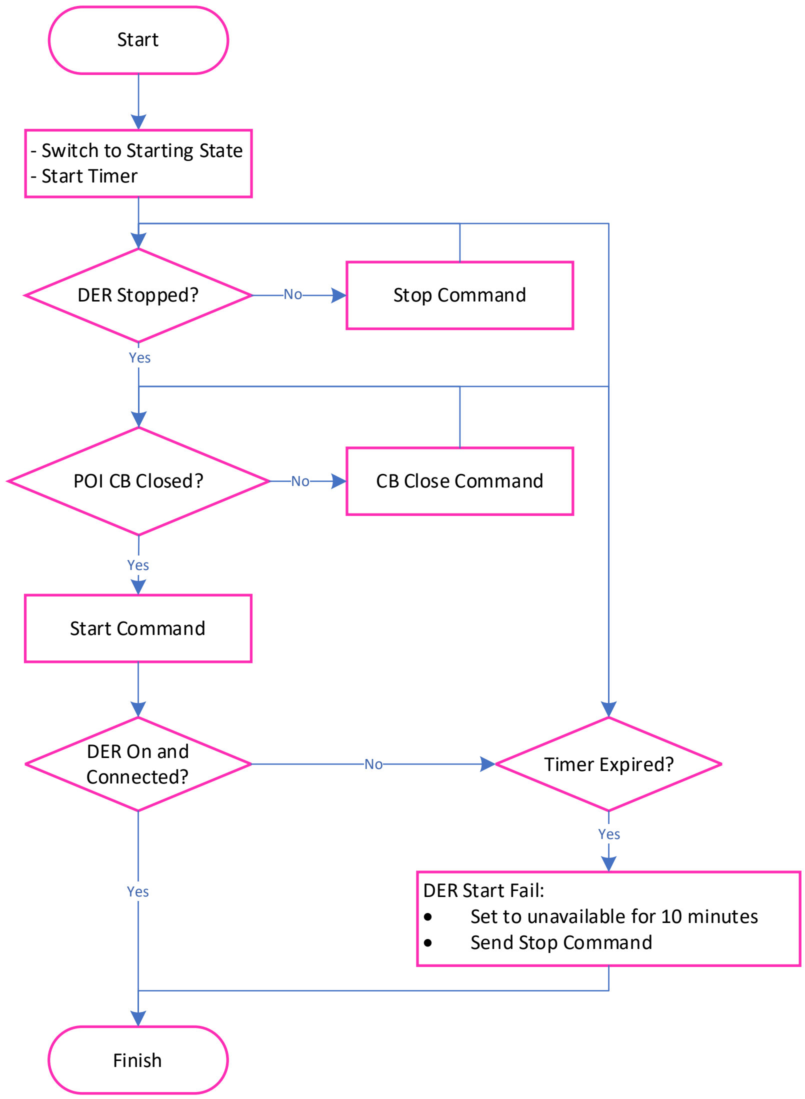

Figure 14- DER Start Sequence

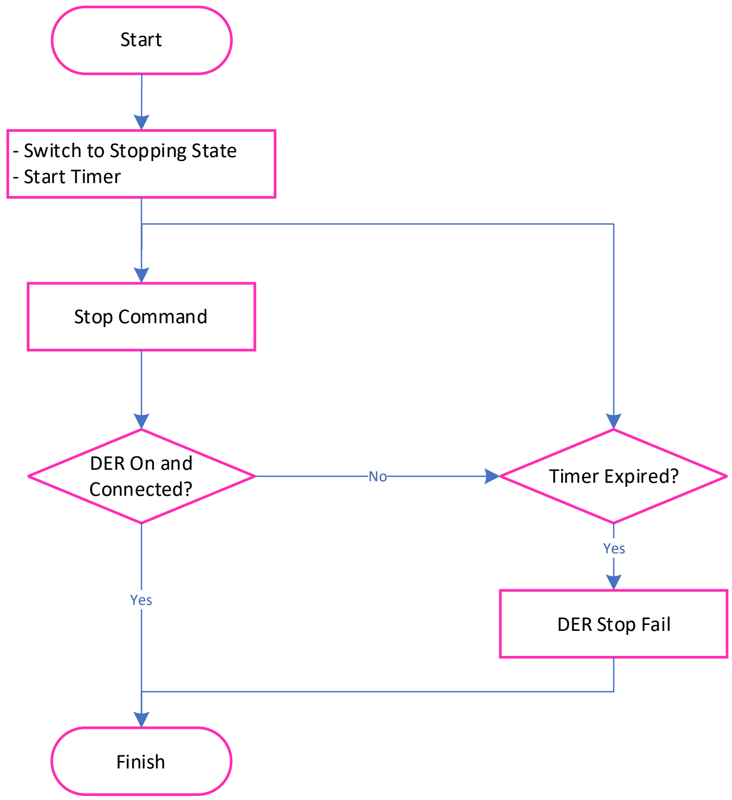

Figure 15- DER Stop Sequence

3.7.2 Open/Close Circuit Breaker

A generic Open/Close Circuit Breaker sequence has been implemented and can be seen in Figure 16 and Figure 17. The sequence sends a 5 second pulse command every 15 seconds at least once and can retry up to a certain number of times adjustable by the operator. If the timer expires and the commands (and retries) have been unsuccessful, a Breaker Fail event is declared. For the DER, this may also result in a Start Fail event and make the DER unavailable for 10 minutes. For the loads, this will also result in the load being unavailable for 10 minutes for switching by the Dispatch function.

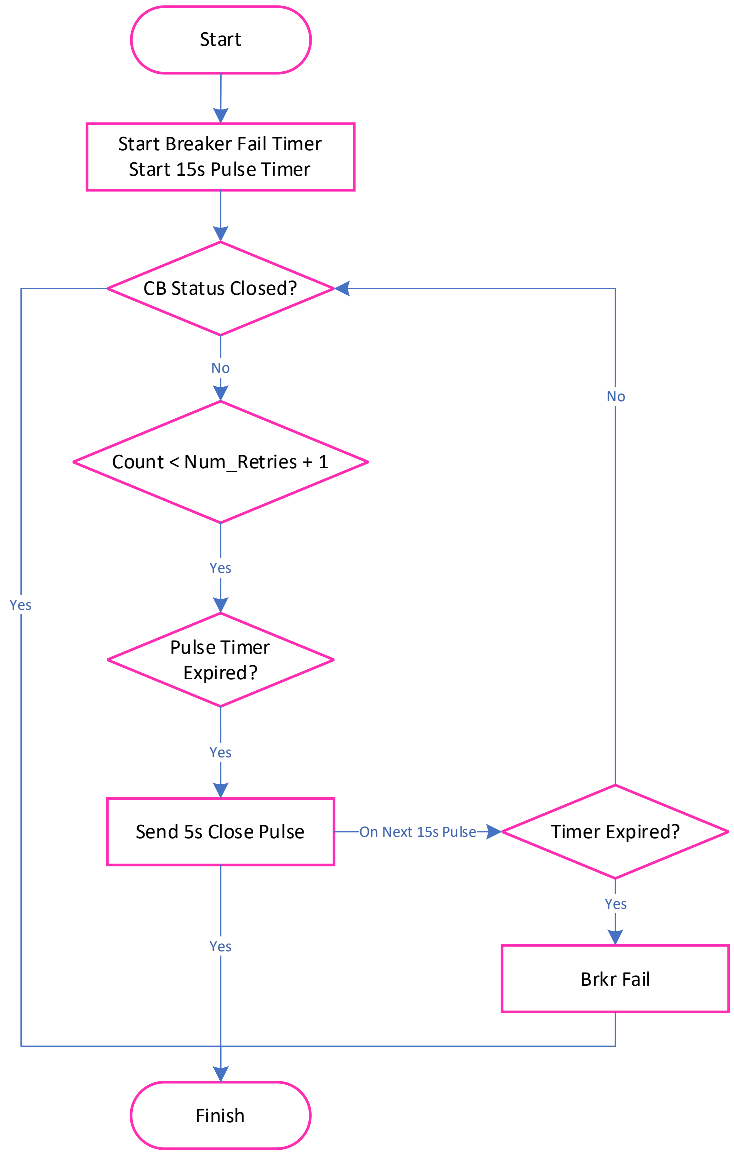

Figure 16- Close Breaker Sequence

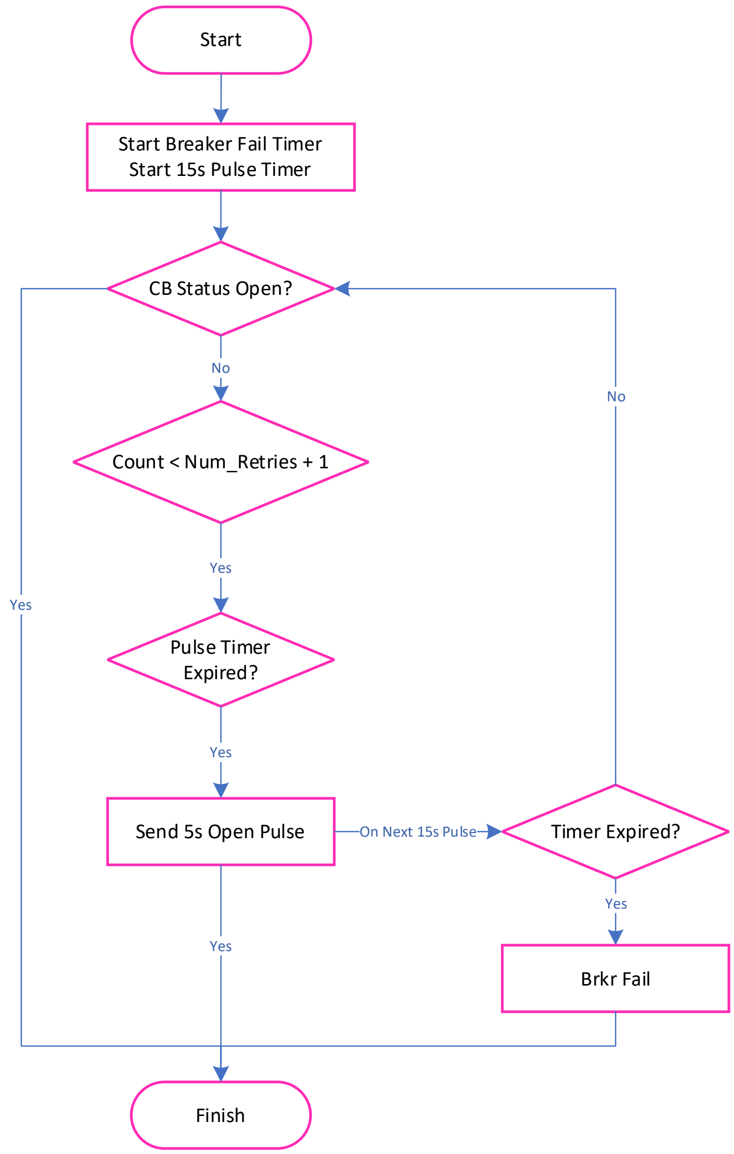

Figure 17- Open Breaker Sequence

3.7.3 Common DER States

The DERs have various states which determine if they are ready to be utilized by the microgrid controller. The following are the various states of the DER identified by the MCS.

- On and connected: The DER is enabled and its breaker is closed.
- Available for connection: The DER is available to be connected.
- Starting: The start command is sent and the DER is executing its start sequence.
- Stopping: The stop command is sent and the DER is executing its stop sequence.
- Test Mode: The test mode feature enables the operator to put any DER in a test mode. This will result in the MCS ignoring all measurements for that DER and all commands will be disabled.

- Start Fail: If a start command has been issued and the DER fails to start within the required time (adjustable for each DER), a Start Fail flag will be asserted and the DER will be made unavailable for 10 minutes.
- Stop Fail: If a stop command has been issued and the DER fails to start within the required time (adjustable for each DER), a Stop Fail flag will be asserted and latched for 10 minutes.
- Initialized: Once Auto mode is enabled and initialized, the DER model will initialize all of its internal variables (e.g. reading and setting Modbus commands, initial values, etc.). Once this process is complete, the Initialized variable will be asserted and all commands for that DER will then be enabled if Auto mode is active.
- Comms Fail Breaker: This flag indicates that the communication to the breaker of minimum one DER has been lost for more than 30 seconds. This will result in the MCS switching to manual mode until communication is restored.
- Comms Fail Controller: This flag indicates that the communication to minimum one DER controller has been lost for more than 30 seconds. This will result in the MCS switching to manual mode until communication is restored.

3.7.4 Common DER Properties

Each DER has a set of common properties that are used by the MCS in the various functions:

- P_{AVG}: The active power for each DER is measured at the Point of Interconnection (POI) breaker and is averaged for a period of t_{AVG} (adjustable by the operator) to filter transient variations.
- P_{MAX}: Each DER has a rated active power that is associated with its operation.
- CB Status: The status of the switchgear Circuit Breaker (Open/Close) associated with the DER

3.8 Specific DER Models

3.8.1 Diesel Generators

The model used by the MCS for the two Diesel Generators can be seen in Figure 18, with the additional properties highlighted.

- RR_D: A downwards regulating reserve is calculated continuously by the DG model and is equal to P_{AVG} if the DG is on and connected.
- RR_U: An upwards regulating reserve is calculated continuously by the DG model and is equal to P_{MAX} - P_{AVG} if the DG is on and connected.

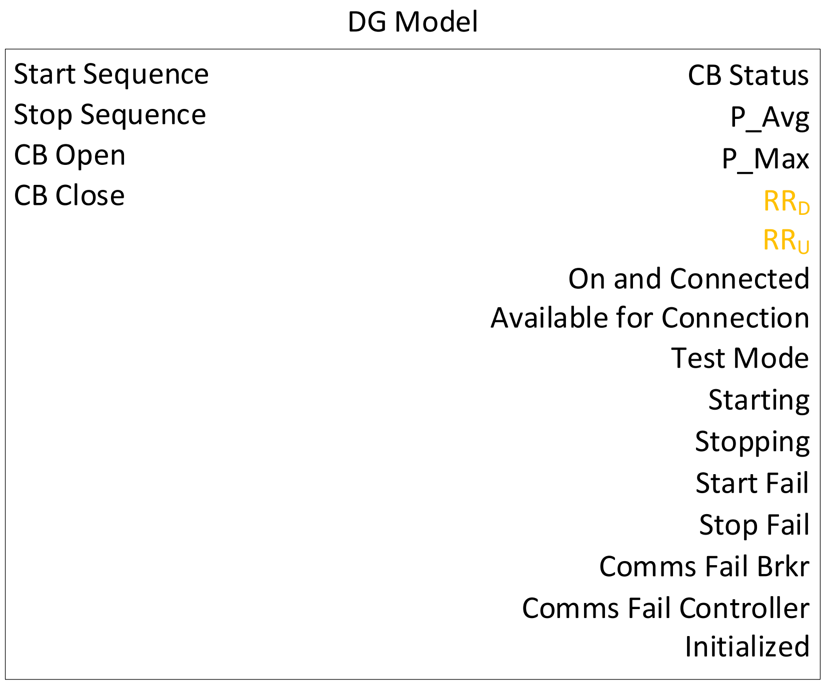

Figure 18- DG Model used by MCS

The logic used to determine if the DG is on and connected or if it is available for connection is shown in Figure 19 and Figure 20 respectively.

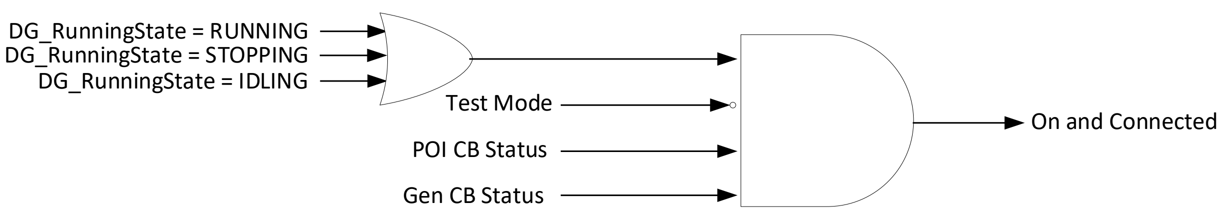

Figure 19- Logic to Determine if DG is On and Connected

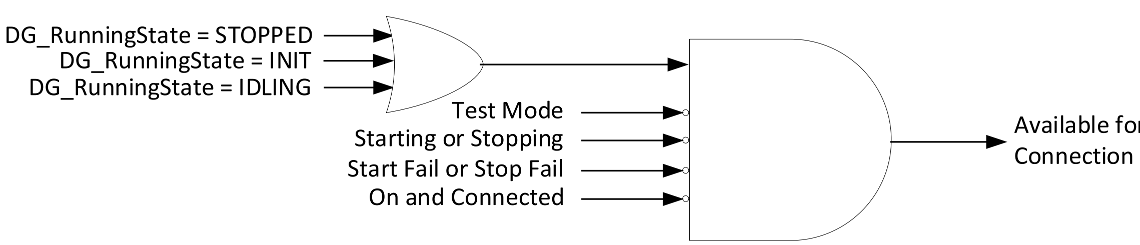

Figure 20- Logic to Determine if DG is Available for Connection

3.8.2 Battery Energy Storage System

The model used by the MCS for the BESS can be seen in Figure 21, with the additional properties and commands highlighted.

- Switch to VSG: This command switches the BESS to VSG mode. If there are DGs on and connected, then the BESS will be in VSG On-grid mode, otherwise it will be in VSG off-grid mode. This distinction between VSG On-grid and Off-grid is handled by the BESS controller.
- Switch to On-Grid: This command switches BESS to On-Grid mode.
- Active Power Setpoint: This setpoint is issued to the BESS controller and is set by the Dispatch/Regulation Reserve Management/Blackstart functions to the appropriate value.
- State_OnGrid: This state variable identifies the current on-grid state of the BESS. This could be On-Grid, VSG On-grid or VSG Off-grid.
- SOC: This indicates the current State of Charge (SOC) of the BESS and can range from 0% to 100%.
- SOC_{MIN}: This indicates the minimum SOC setting applied on the BESS controller. Below this SOC, the BESS controller will not generate any power into the grid.
- SOC_{MAX}: This indicates the maximum SOC setting applied on the BESS controller. Above this SOC, the BESS controller will absorb any power from the grid.
- RR_D: A downwards regulating reserve is calculated continuously by the BESS model using the flowchart shown in Figure 22 if the BESS is on and connected.
- RR_U: An upwards regulating reserve is calculated continuously by the BESS model using the flowchart shown in Figure 22 if the BESS is on and connected.

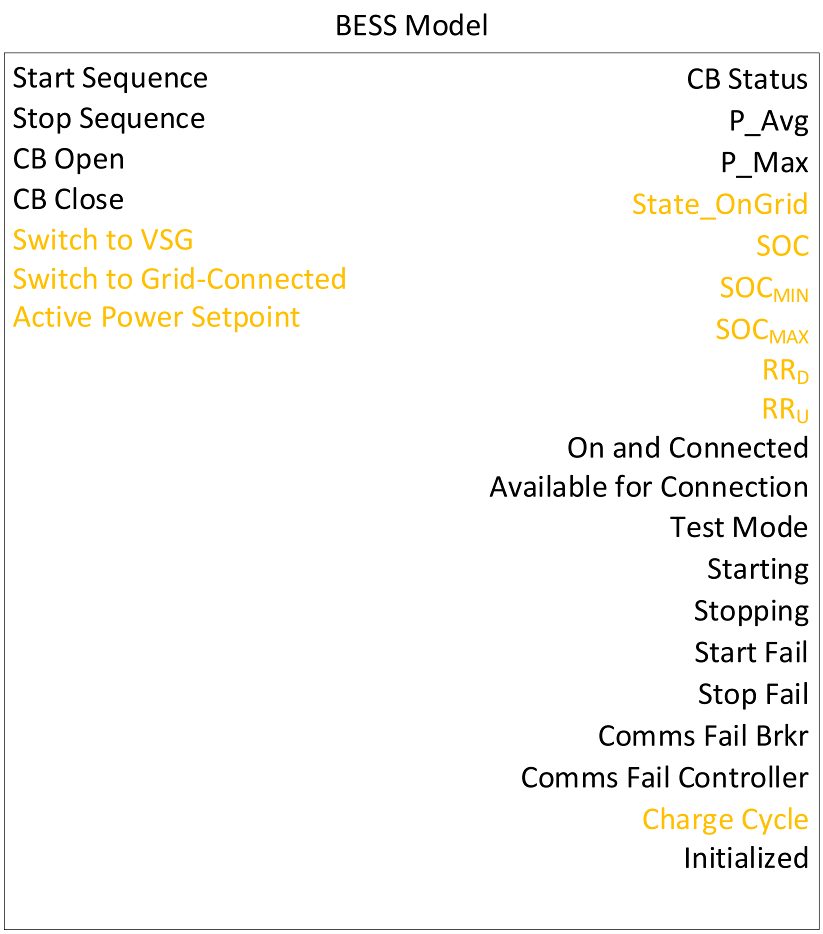

Figure 21- BESS Model used by MCS

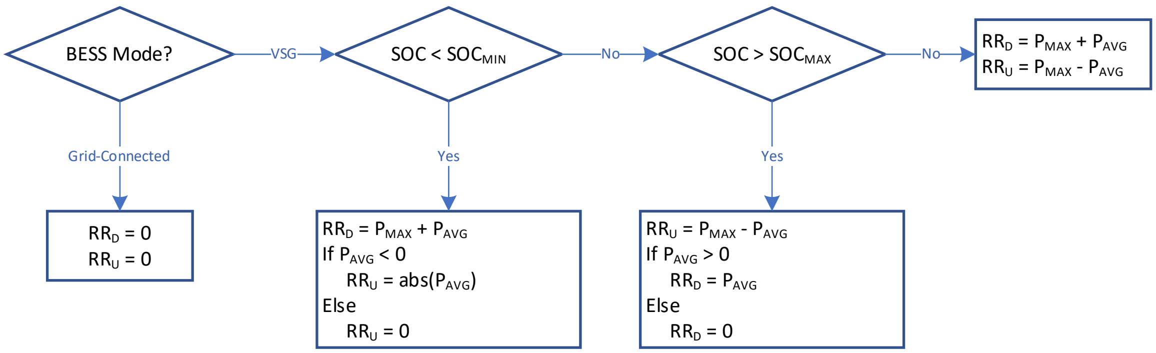

Figure 22- Regulation Reserve Calculation for BESS

The logic used to determine if the BESS is on and connected or if it is available for connection is shown in Figure 23 and Figure 24 respectively.

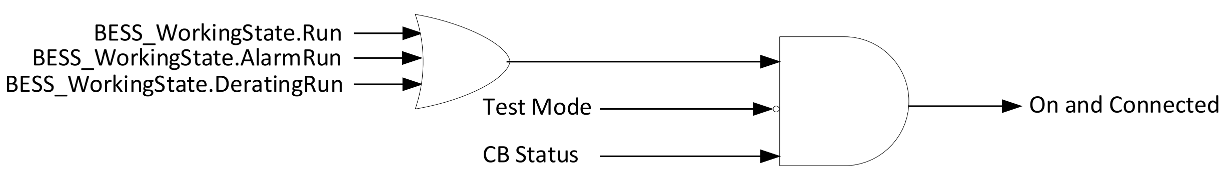

Figure 23- Logic to Determine if the BESS is On and Connected

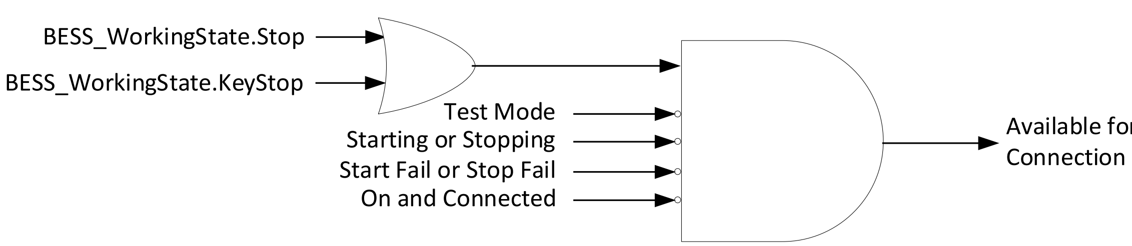

Figure 24- Logic to Determine if the BESS is Available for Connection

3.8.3 PV

The model used by the MCS for the PV can be seen in Figure 25. The PV model consists of five individual inverter strings that are aggregated into one PV model. The additional parameters modeled are highlighted

- Active Power Limit Setpoint: Provides the limit on the active power that the PV should generate. The appropriate limit to apply to each inverter is calculated based on the amount of inverters that are on and connected and/or available for connection (depending on whether curtailment is applied in the On and Connected state or in the Available for Connection state).

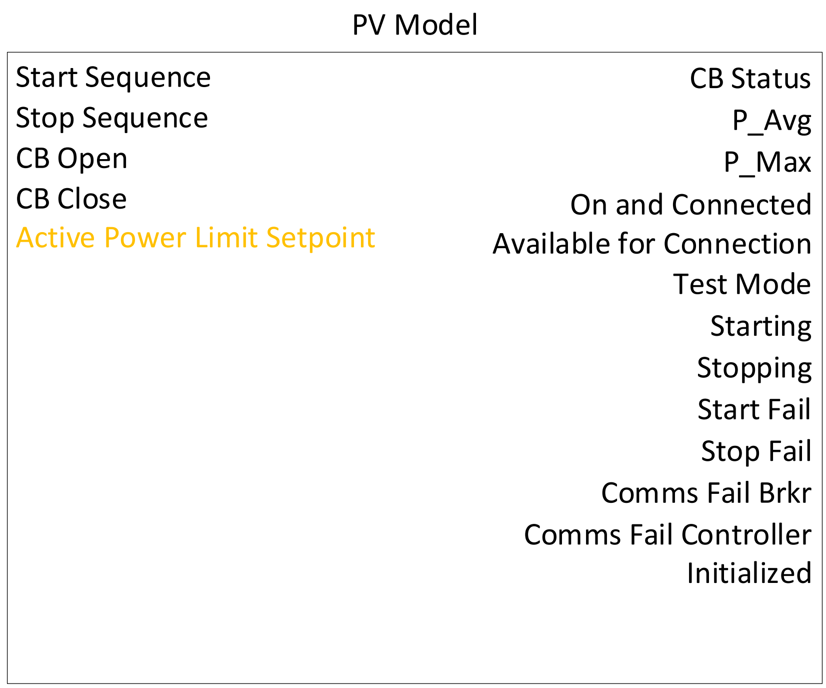

Figure 25- PV Model used by MCS

The logic used to determine if each PV inverter is on and connected or if it is available for connection are shown in Figure 26 and Figure 27 respectively. The logic used to determine if the PV DER is on and connected or if it available for connection are shown in Figure 28 and Figure 29 respectively and is derived from the individual PV inverter states.

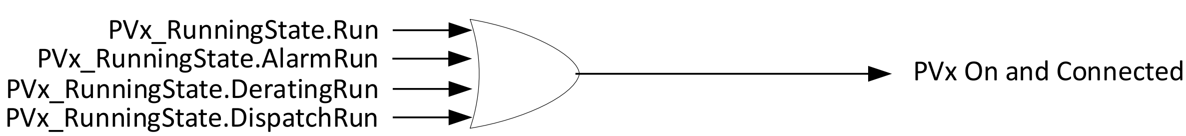

Figure 26- Logic to Determine if each PV Inverter is On and Connected

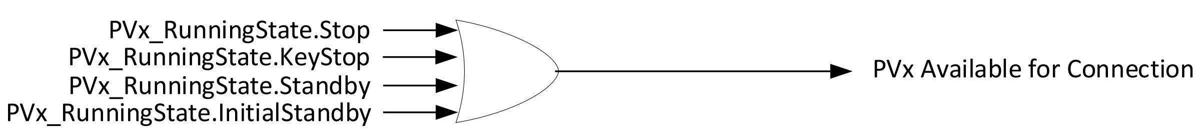

Figure 27- Logic to Determine if each PV Inverter is Available for Connection

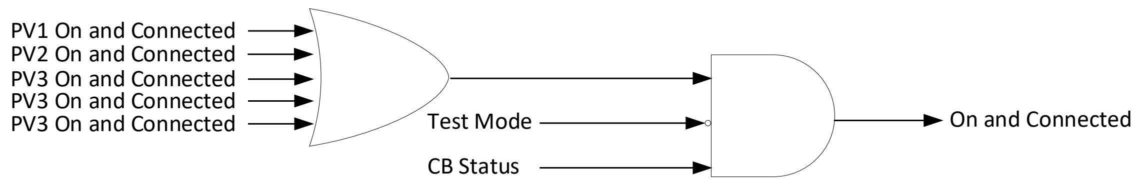

Figure 28- Logic to Determine if the PV is On and Connected

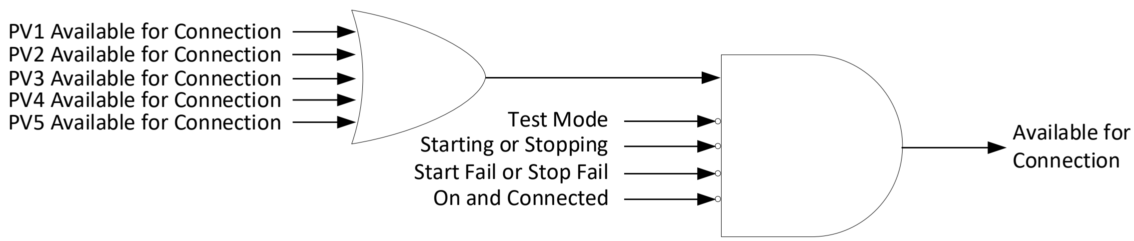

Figure 29- Logic to Determine if the PV is Available for Connection

3.8.4 Wind

The model used by the MCS for the Wind can be seen in Figure 30 with the additional parameters modeled highlighted

- Active Power Limit Setpoint: Provides the limit on the active power that the Wind should generate.

Wind Model

Start Sequence	CB Status
Stop Sequence	P_Avg
CB Open	P_Max
CB Close	On and Connected
Active Power Limit Setpoint	Available for Connection
	Test Mode
	Starting
	Stopping
	Start Fail
	Stop Fail
	Comms Fail Brkr
	Comms Fail Controller
	Initialized

Figure 30- Wind Model used by MCS

The logic used to determine if the Wind is on and connected or if it is available for connection is shown in Figure 31 and Figure 32 respectively.

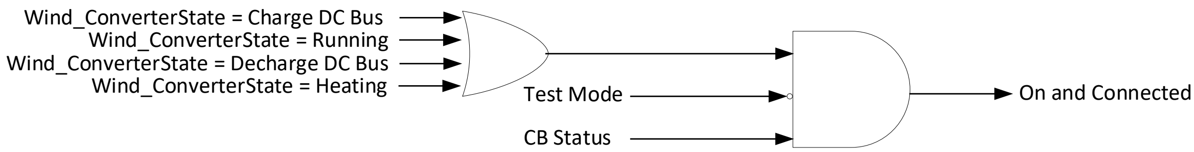

Figure 31- Logic to Determine if the Wind is On and Connected

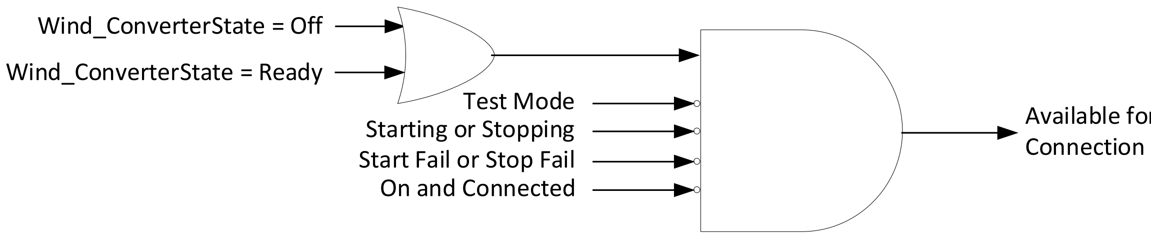

Figure 32- Logic to Determine if the Wind is Available for Connection

4 MODBUS POINTS MAPPING

This section presents the Modbus points mapping of MCS in master and slave mode of communication. In the master Modbus operation, the MCS receives the measurements and status of the microgrid through the concentrator. In the master slave of communication, the MCS provides its internal variables and calculations to the concentrator which will be used in the HMI.

4.1.1 Master Point List

4.1.1.1 Write Bits

Address	Controller	Description	Type
1	DG4	Circuit Breaker Open	Pulse
2	DG4	Circuit Breaker Close	Pulse
3	DG4	StartStop	Latched
11	DG5	Circuit Breaker Open	Pulse
12	DG5	Circuit Breaker Close	Pulse
13	DG5	StartStop	Latched
21	Wind	Circuit Breaker Open	Pulse
22	Wind	Circuit Breaker Close	Pulse
23	Wind	Curtail	Latched
24	Wind	Enable Remote Control	Latched
31	BESS	Circuit Breaker Open	Pulse
32	BESS	Circuit Breaker Close	Pulse
41	PV	Circuit Breaker Open	Pulse
42	PV	Circuit Breaker Close	Pulse
43	PV	PV1-StartStop	Latched
44	PV	PV2-StartStop	Latched
45	PV	PV3-StartStop	Latched
46	PV	PV4-StartStop	Latched
47	PV	PV5-StartStop	Latched
101	LOAD1	Circuit Breaker Open	Pulse
102	LOAD1	Circuit Breaker Close	Pulse
111	LOAD1	Circuit Breaker Open	Pulse
112	LOAD1	Circuit Breaker Close	Pulse

4.1.1.2 *Write Registers*

Address	Controller	Description	Range/Meaning	Units
21	Wind	Curtailment Setpoint - Active Power	Active Power Limit setpoint for Wind	kW
22	Wind	StartStop Upper 16-bit Register	Start/Stop Command for Wind. See Wind_StartStopCmd Enumeration.	
23	Wind	StartStop Lower 16-bit Register		
31	BESS	Active Power Setpoint (Grid-Connected)	Active Power Setpoint for BESS for Grid-Connected Mode	kW
32	BESS	GridMode	Grid Mode Command for BESS. See BESS_GridMode_Cmd Enumeration.	
33	BESS	StartStop	Start/Stop Command for BESS. See BESS_StartStop_Cmd Enumeration	
34	BESS	OnGridMode	On Grid Mode Command for BESS. Default to On-Grid Constand Power (AC). See BESS_OnGridMode_Cmd Enumeration	
35	BESS	Future: Active Power Setpoint (VSG)	Active Power Setpoint for BESS for VSG Mode Not implemented in current version. Will be implemented once BESS firmware is updated and VSG is activated.	kW
36	BESS	Standby Mode	Standby Command for BESS. See BESS_Standby_Cmd Enumeration	
41	PV	PV1 - Curtailment Setpoint - Active Power	Active Power Limit setpoint for PV Inverter 1	kW
42	PV	PV2 - Curtailment Setpoint - Active Power	Active Power Limit setpoint for PV Inverter 2	kW
43	PV	PV3 - Curtailment Setpoint - Active Power	Active Power Limit setpoint for PV Inverter 3	kW
44	PV	PV4 - Curtailment Setpoint - Active Power	Active Power Limit setpoint for PV Inverter 4	kW
45	PV	PV5 - Curtailment Setpoint - Active Power	Active Power Limit setpoint for PV Inverter 5	kW

4.1.1.3 Input Bits

Address	Controller	Description	Range/Meaning
1	DG4	Comms Failure of Controller	0: Comms OK 1: Comms Fail
2	DG4	Comms Failure of ECP Breaker	0: Comms OK 1: Comms Fail
11	DG5	Comms Failure of Controller	0: Comms OK 1: Comms Fail
12	DG5	Comms Failure of ECP Breaker	0: Comms OK 1: Comms Fail
21	Wind	Comms Failure of Controller	0: Comms OK 1: Comms Fail
22	Wind	Comms Failure of ECP Breaker	0: Comms OK 1: Comms Fail
23	Wind	Converter Enabled	0: Converter Disabled 1: Converter Enabled
31	BESS	Comms Failure of Controller	0: Comms OK 1: Comms Fail
32	BESS	Comms Failure of ECP Breaker	0: Comms OK 1: Comms Fail
41	PV	Comms Failure of Controller	0: Comms OK 1: Comms Fail
42	PV	Comms Failure of ECP Breaker	0: Comms OK 1: Comms Fail
43	PV	PV1-Run	Running State for PV Inverter 1
44	PV	PV1-Stop	
45	PV	PV1-Key Stop	
46	PV	PV1-Emergency Stop	
47	PV	PV1-Standby	
48	PV	PV1-Initial Standby	
49	PV	PV1-Starting	
50	PV	PV1-Alarm Run	
51	PV	PV1-Derating Run	
52	PV	PV1-Dispatch Run	
53	PV	PV1-Communication Status	
54	PV	PV2-Run	Running State for PV Inverter 2
55	PV	PV2-Stop	
56	PV	PV2-Key Stop	
57	PV	PV2-Emergency Stop	

Address	Controller	Description	Range/Meaning
58	PV	PV2-Standby	
59	PV	PV2-Initial Standby	
60	PV	PV2-Starting	
61	PV	PV2-Alarm Run	
62	PV	PV2-Derating Run	
63	PV	PV2-Dispatch Run	
64	PV	PV2-Communication Status	
65	PV	PV3-Run	Running State for PV Inverter 3
66	PV	PV3-Stop	
67	PV	PV3-Key Stop	
68	PV	PV3-Emergency Stop	
69	PV	PV3-Standby	
70	PV	PV3-Initial Standby	
71	PV	PV3-Starting	
72	PV	PV3-Alarm Run	
73	PV	PV3-Derating Run	
74	PV	PV3-Dispatch Run	
75	PV	PV3-Communication Status	
76	PV	PV4-Run	Running State for PV Inverter 4
77	PV	PV4-Stop	
78	PV	PV4-Key Stop	
79	PV	PV4-Emergency Stop	
80	PV	PV4-Standby	
81	PV	PV4-Initial Standby	
82	PV	PV4-Starting	
83	PV	PV4-Alarm Run	
84	PV	PV4-Derating Run	
85	PV	PV4-Dispatch Run	
86	PV	PV4-Communication Status	
87	PV	PV5-Run	Running State for PV Inverter 5
88	PV	PV5-Stop	
89	PV	PV5-Key Stop	
90	PV	PV5-Emergency Stop	
91	PV	PV5-Standby	
92	PV	PV5-Initial Standby	
93	PV	PV5-Starting	
94	PV	PV5-Alarm Run	

Address	Controller	Description	Range/Meaning
95	PV	PV5-Derating Run	
96	PV	PV5-Dispatch Run	
97	PV	PV5-Communication Status	
101	LOAD1	Comms Failure	0: Comms OK 1: Comms Fail
111	LOAD2	Comms Failure	0: Comms OK 1: Comms Fail
121	MCS	RemoteLocal	0: Remote 1: Local

4.1.1.4 *Input Registers*

Address	Controller	Description	Range/Meaning	Units
1	DG4	Active Power	POI Circuit Breaker Active Power Measurement	kW
2	DG4	Reactive Power	POI Circuit Breaker Reactive Power Measurement	kVAR
3	DG4	RunningState	Running state received from EMCP4.2 controller. Used by MCS to determine the state of the DG. See DG_RunningState Enumeration	
4	DG4	Circuit Breaker Status	State of the POI Circuit Breaker 01 - Open 10 - Closed	
5	DG4	Gen Circuit Breaker Status	State of the Generator Circuit Breaker (i.e. synch check breaker) 01 - Open 10 - Closed	
6	DG4	Gen Operating Time	Total running time of the DG	Hours
7	DG4	Fuel Level	Fuel Level of the DG	%
8	DG4	Engine Control Switch Position	Used to determine if the DG is available for connection. Needs to be set to AUTO for remote start. See DG_ECSState Enumeration	
11	DG5	Active Power	POI Circuit Breaker Active Power Measurement	kW
12	DG5	Reactive Power	POI Circuit Breaker Reactive Power Measurement	kVAR
13	DG5	RunningState	Running state received from EMCP4.2 controller. Used by MCS to determine the state of the DG. See DG_RunningState Enumeration	
14	DG5	Circuit Breaker Status	State of the POI Circuit Breaker 01 - Open 10 - Closed	
15	DG5	Gen Circuit Breaker Status	State of the Generator Circuit Breaker (i.e. synch check breaker) 01 - Open 10 - Closed	
16	DG5	Gen Operating Time	Total running time of the DG	Hours
17	DG5	Fuel Level	Fuel Level of the DG	%

Address	Controller	Description	Range/Meaning	Units
18	DG5	Engine Control Switch Position	Used to determine if the DG is available for connection. Needs to be set to AUTO for remote start. See DG_ECSState Enumeration	
21	Wind	Active Power	POI Circuit Breaker Active Power Measurement	kW
22	Wind	Reactive Power	POI Circuit Breaker Reactive Power Measurement	kVAR
23	Wind	ConverterState	Used to determine the state of the Wind. See Wind_ConverterState enumeration	
24	Wind	Circuit Breaker Status	State of the POI Circuit Breaker 01 - Open 10 - Closed	
31	BESS	Active Power	POI Circuit Breaker Active Power Measurement	kW
32	BESS	Reactive Power	POI Circuit Breaker Reactive Power Measurement	kVAR
33	BESS	State of Charge	State of Charge of the BESS (0 - 100%)	%
34	BESS	Circuit Breaker Status	State of the POI Circuit Breaker 01 - Open 10 - Closed	
35	BESS	WorkingMode	Current on-grid mode of the BESS. See BESS_WorkingMode enumeration.	
36	BESS	WorkingState	Working state of the BESS. See BESS_WorkingState enumeration.	
37	BESS	RemoteLocal	Indicates whether the BESS is in Remote / Local mode. See BESS_RemoteLocal enumeration.	
38	BESS	SOC - Lower Limit	Lower Limit on SOC applied on the BESS controller	%
39	BESS	SOC - Upper Limit	Upper Limit on SOC applied on the BESS controller	%
41	PV	PV1 - Active Power	Active power measurement for PV Inverter 1	kW
42	PV	PV1 - Reactive Power	Reactive power measurement for PV Inverter 1	kVAR
43	PV	PV2 - Active Power	Active power measurement for PV Inverter 2	kW
44	PV	PV2 - Reactive Power	Reactive power measurement for PV Inverter 2	kVAR
45	PV	PV3 - Active Power	Active power measurement for PV Inverter 3	kW
46	PV	PV3 - Reactive Power	Reactive power measurement for PV Inverter 3	kVAR
47	PV	PV4 - Active Power	Active power measurement for PV Inverter 4	kW
48	PV	PV4 - Reactive Power	Reactive power measurement for PV Inverter 4	kVAR

Address	Controller	Description	Range/Meaning	Units
49	PV	PV5 - Active Power	Active power measurement for PV Inverter 5	kW
50	PV	PV5 - Reactive Power	Reactive power measurement for PV Inverter 5	kVAR
51	PV	PV Circuit Breaker - Active Power	POI Circuit Breaker Active Power Measurement	kW
52	PV	PV Circuit Breaker - Reactive Power	POI Circuit Breaker Reactive Power Measurement	kVAR
58	PV	Circuit Breaker Status	State of the POI Circuit Breaker 01 - Open 10 - Closed	
101	LOAD1	Active Power	POI Circuit Breaker Active Power Measurement	
102	LOAD1	Reactive Power	POI Circuit Breaker Reactive Power Measurement	
103	LOAD1	Circuit Breaker Status	State of the POI Circuit Breaker 01 - Open 10 - Closed	
110	LOAD2	Active Power	POI Circuit Breaker Active Power Measurement	
111	LOAD2	Reactive Power	POI Circuit Breaker Reactive Power Measurement	
112	LOAD2	Circuit Breaker Status	State of the POI Circuit Breaker 01 - Open 10 - Closed	

4.1.1.5 Enumerations

DG_RunningState	
0	INIT
1	PRE_CRANK
2	STARTING
3	RUNNING
4	PRE_COOLDOWN
5	COOLDOWN
6	STOPPING
7	STOPPED
8	IDLING

DG_ECSState	
0	STOP
1	AUTO
2	RUN

Wind_ConverterState	
0	Off
1	Chrg DC Bus
3	Ready
6	Running
9	Dchrg DC Bus
10	Heating
20	Fault
30	Unknown

BESS_WorkingMode	
0	On-grid Constant Current
1	On-grid Constant Voltage
2	On-Grid Constant Power (AC)
3	On-Grid Constant Power (DC)
TBC	Future: VSG Off-Grid
TBC	Future: VSG On-Grid

BESS_WorkingState (Bit State)	
0	Self-Checking
1	Microgrid Power Supply Starting
2	Grid Power Supply Starting
3	Microgrid Power Supply Running
4	Grid Power Supply Running
5	Fault
6	Stopping
7	Stopped
8	Reserved
9	Reserved
10	Reserved
11	Reserved
12	Reserved
13	Reserved
14	Reserved
15	Reserved

BESS_RemoteLocal	
0	Remote/Local
1	Remote
2	Local

Wind_StartStop_Cmd	
65470466	Reset
65470484	Stop
65470485	Start
65470492	Emergency Test

BESS_GridMode_Cmd	
0	On-Grid Mode
1	Off-Grid Mode
TBC	Future: VSG Mode

BESS_StartStop_Cmd	
1	Stop
2	Start

BESS_OnGridMode_Cmd	
0x00	On-grid Constant Current
0x01	On-grid Constant Voltage
0x02	On-grid Constant Power (AC)
0x03	On-grid Constant Power (DC)

BESS_standby cmd	
0xAA (170)	PCS standby
0x55 (85)	PCS exit standby

4.1.2 Slave Point List

4.1.2.1 *Write Bits*

Address	Description	Range/Meaning
1	Auto Mode	0: Manual 1: Auto
2	Dispatch Allow Switching	0: Dispatch algorithm will not close any breakers for the BESS, PV, Wind or Loads 1: Dispatch algorithm will close the breakers for the BESS, PV, Wind or Loads if available for connection
3	Dispatch Curtail Priority	0: PV 1: Wind
4	Dispatch: Periodic BESS Discharge	0: Disabled 1: Enabled. If the BESS SOC remains above SOC_{MIN} + (SOC_{MAX} - SOC_{MIN}) / 2, then switch to a discharge-only mode. The BESS will switch back to charge mode once the SOC drops below SOC_Min
5	Future: Blackstart Priority	0: DG 1: BESS Not implemented in current revision, will be updated once BESS VSG mode has been enabled by vendor. Default to DG. Contact GE for assistance.
6	Future: Blackstart Priority Autoswitch Enable	0: Algorithm will not be able to switch the Blackstart Priority if the device is not available for connection 1: Algorithm will be able to switch the Blackstart Priority if the device is not available for connection Not implemented in current revision, will be updated once BESS VSG mode has been enabled by vendor. Default to disabled. Contact GE for assistance.
7	DG4: Test Mode	0: All measurements and statuses will be considered, and controls will be enabled 1: Measurements will be considered to be 0 and breaker assumed to be open, Controls will be disabled
8	DG5: Test Mode	0: All measurements and statuses will be considered, and controls will be enabled 1: Measurements will be considered to be 0 and breaker assumed to be open, Controls will be disabled

Address	Description	Range/Meaning
9	BESS: Test Mode	0: All measurements and statuses will be considered, and controls will be enabled 1: Measurements will be considered to be 0 and breaker assumed to be open, Controls will be disabled
10	PV: Test Mode	0: All measurements and statuses will be considered, and controls will be enabled 1: Measurements will be considered to be 0 and breaker assumed to be open, Controls will be disabled
11	Wind: Test Mode	0: All measurements and statuses will be considered, and controls will be enabled 1: Measurements will be considered to be 0 and breaker assumed to be open, Controls will be disabled
12	LD1: Test Mode	0: All measurements and statuses will be considered, and controls will be enabled 1: Measurements will be considered to be 0 and breaker assumed to be open, Controls will be disabled
13	LD2: Test Mode	0: All measurements and statuses will be considered, and controls will be enabled 1: Measurements will be considered to be 0 and breaker assumed to be open, Controls will be disabled

4.1.2.2 Write Registers

Address	Description	Units	Default	Min	Max	Scale	Comments
1	Dispatch: Cycle Time	s	120	120	600	1	Cycle time of the Dispatch function.
2	Dispatch: DG Min Load	kW	250	150	300	1	Target Minimum Load for DG, used by the Dispatch and Regulation Reserve Management functions
3	Dispatch: DG Max Load	kW	300	200	350	1	Target Maximum Load for DG, used by the Dispatch and Regulation Reserve Management functions
4	Dispatch: Min BESS SOC	%	20	10	40	1	Target Minimum SOC for BESS, used by the Dispatch and Regulation Reserve Management functions
5	Dispatch: Max BESS SOC	%	80	60	90	1	Target Maximum SOC for BESS, used by the Dispatch and Regulation Reserve Management functions
6	Regulation Reserve Management: Cycle Time	s	30	30	60	1	Cycle time of the Regulation Reserve Management Function

Address	Description	Units	Default	Min	Max	Scale	Comments
7	Regulation Reserve Management: Required Regulation Reserve Downwards	kW	200	100	200	1	Downwards Regulating Reserve Required. Target used by the Dispatch and Regulation Reserve Management functions.
8	Regulation Reserve Management: Required Regulation Reserve Upwards	kW	200	100	200	1	Upwards Regulating Reserve Required. Target used by the Dispatch and Regulation Reserve Management functions.
9	Blackstart: Max Retries		2	0	2	1	Maximum number of retries allowed for the Blackstart function following an unsuccessful Blackstart.
10	Blackstart: PV Ramp Wait Time	s	30	30	60	1	Amount of time that the Blackstart function should wait for the PV to ramp to full capacity
11	Blackstart: Wind Ramp Wait Time	s	60	60	300	1	Amount of time that the Blackstart function should wait for the Wind to ramp to full capacity
12	DG_StartFail_Time	s	300	300	600	1	The amount of time that the MCS should wait for the DG to start up. If the DG does not start in this amount of time, a start fail will be declared.
13	DG_StopFail_Time	s	300	300	600	1	The amount of time that the MCS should wait for the DG to stop. If the DG does not stop in this amount of time, a stop fail will be declared.
14	BESS_StartFail_Time	s	60	60	300	1	The amount of time that the MCS should wait for the BESS to start up. If the BESS does not start in this amount of time, a start fail will be declared.
15	BESS_StopFail_Time	s	60	60	300	1	The amount of time that the MCS should wait for the BESS to stop. If the BESS does not stop in this amount of time, a stop fail will be declared.
16	BESS_CosPhi		900	800	1000	0.001	The power factor at which the BESS is operated. This is used to determine the P_{MAX} to use for the BESS.
17	PV_StartFail_Time	s	60	60	300	1	The amount of time that the MCS should wait for the PV to start up. If the PV does not start in this amount of time, a start fail will be declared.

Address	Description	Units	Default	Min	Max	Scale	Comments
18	PV_StopFail_Time	s	60	60	300	1	The amount of time that the MCS should wait for the PV to stop. If the PV does not stop in this amount of time, a stop fail will be declared.
19	Wind_StartFail_Time	s	60	60	300	1	The amount of time that the MCS should wait for the Wind to start up. If the Wind does not start in this amount of time, a start fail will be declared.
20	Wind_StopFail_Time	s	60	60	300	1	The amount of time that the MCS should wait for the Wind to stop. If the Wind does not stop in this amount of time, a stop fail will be declared.
21	Brkr_Open_Retries		2	0	2	1	The number of retries allowed for Brkr Open commands for each DER and load.
22	Brkr_Close_Retries		2	0	2	1	The number of retries allowed for Brkr Close commands for each DER and load.
23	Moving Average Time	s	10	10	20	1	The time used to calculate the moving average for each DER.
24	Load_Snapshot_Time	s	300	300	600	1	The time used to take snapshots for the load. Used by the Blackstart function.
25	CommsFail_Time	s	30	30	60	1	The amount of time to wait before declaring a comms fail condition.

4.1.2.3 Input Bits

Address	Description	Range/Meaning
1	Auto Mode Active	0: Manual Mode 1: Auto Mode
2	Auto Mode Initializing	0: Not Initializing / Initialized 1: Initializing
3	Regulation Reserve Down Low	0: Regulation Reserve above required level 1: Regulation Reserve below required level
4	Regulation Reserve Up Low	0: Regulation Reserve above required level 1: Regulation Reserve below required level
5	Dispatch Active	0: Dispatch Function Not Active 1: Dispatch Function Active
6	Dispatch Alarm	0: No Alarm 1: Alarm Generated (See AlarmReason for details)
7	Dispatch: Curtail Apply	0: Apply Curtailment not requested 1: Apply Curtailment requested by Dispatch / Regulation Reserve Management Functions
8	Dispatch: Curtail Remove	0: Curtail Algorithm Not Remove 1: Curtail Algorithm Remove
9	Dispatchable System	0: Microgrid not Dispatchable 1: Microgrid Dispatchable A Dispatchable Microgrid requires at least one grid-forming DER with one load and a minimum load of 10kW
10	Regulation Reserve Management Active	0: Regulation Reserve Management Function Not Active 1: Regulation Reserve Management Function Active
11	Regulation Reserve Management Alarm	0: No Alarm 1: Alarm Generated (See AlarmReason for details)
12	Operating Mode: Dispatch and Regulation Reserve Management	0: Mode 1 (BESS Grid-forming) 1: Mode 2 (DG Grid-forming)
13	Operating Mode: BlackStart	0: Mode 1 (BESS Grid-forming) 1: Mode 2 (DG Grid-forming)
14	BlackStart Active	0: Blackstart Function Not Active 1: Blackstart Function Active
15	BlackStart Alarm	0: No Alarm 1: Alarm Generated (See AlarmReason for details)
16	DG4: Start Requested	0: DG4 Start Not Requested 1: DG4 Start Requested
17	DG4: Stop Requested	0: DG4 Stop Not Requested 1: DG4 Stop Requested
18	DG4: On and Connected	0: DG4 Not On and Connected 1: DG4 On and Connected

Address	Description	Range/Meaning
19	DG4: Available for Connection	0: DG4 Not Available for Connection 1: DG4 Available for Connection
20	DG4: Starting	0: DG4 Not Starting 1: DG4 Starting
21	DG4: Stopping	0: DG4 Not Stopping 1: DG4 Stopping
22	DG4: Start Fail	0: DG4 Not Start Fail 1: DG4 Start Fail
23	DG4: Stop Fail	0: DG4 Not Stop Fail 1: DG4 Stop Fail
24	DG4: Initialized	0: DG4 Not Initialized 1: DG4 Initialized
25	DG5: Start Requested	0: DG5 Start Not Requested 1: DG5 Start Requested
26	DG5: Stop Requested	0: DG5 Stop Not Requested 1: DG5 Stop Requested
27	DG5: On and Connected	0: DG5 Not On and Connected 1: DG5 On and Connected
28	DG5: Available for Connection	0: DG5 Not Available for Connection 1: DG5 Available for Connection
29	DG5: Starting	0: DG5 Not Starting 1: DG5 Starting
30	DG5: Stopping	0: DG5 Not Stopping 1: DG5 Stopping
31	DG5: Start Fail	0: DG5 Not Start Fail 1: DG5 Start Fail
32	DG5: Stop Fail	0: DG5 Not Stop Fail 1: DG5 Stop Fail
33	DG5: Initialized	0: DG5 Not Initialized 1: DG5 Initialized
34	BESS: Start Requested	0: BESS Start Not Requested 1: BESS Start Requested
35	BESS: Stop Requested	0: BESS Stop Not Requested 1: BESS Stop Requested
36	BESS: On and Connected	0: BESS Not On and Connected 1: BESS On and Connected
37	BESS: Available for Connection	0: BESS Not Available for Connection 1: BESS Available for Connection
38	BESS: Starting	0: BESS Not Starting 1: BESS Starting
39	BESS: Stopping	0: BESS Not Stopping 1: BESS Stopping

Address	Description	Range/Meaning
40	BESS: Start Fail	0: BESS Not Start Fail 1: BESS Start Fail
41	BESS: Stop Fail	0: BESS Not Stop Fail 1: BESS Stop Fail
42	BESS: Initialized	0: BESS Not Initialized 1: BESS Initialized
43	PV: Start Requested	0: PV Start Not Requested 1: PV Start Requested
44	PV: Stop Requested	0: PV Stop Not Requested 1: PV Stop Requested
45	PV: On and Connected	0: PV Not On and Connected 1: PV On and Connected
46	PV: Available for Connection	0: PV Not Available for Connection 1: PV Available for Connection
47	PV: Starting	0: PV Not Starting 1: PV Starting
48	PV: Stopping	0: PV Not Stopping 1: PV Stopping
49	PV: Start Fail	0: PV Not Start Fail 1: PV Start Fail
50	PV: Stop Fail	0: PV Not Stop Fail 1: PV Stop Fail
51	PV: Initialized	0: PV Not Initialized 1: PV Initialized
52	Wind: Start Requested	0: Wind Start Not Requested 1: Wind Start Requested
53	Wind: Stop Requested	0: Wind Stop Not Requested 1: Wind Stop Requested
54	Wind: On and Connected	0: Wind Not On and Connected 1: Wind On and Connected
55	Wind: Available for Connection	0: Wind Not Available for Connection 1: Wind Available for Connection
56	Wind: Starting	0: Wind Not Starting 1: Wind Starting
57	Wind: Stopping	0: Wind Not Stopping 1: Wind Stopping
58	Wind: Start Fail	0: Wind Not Start Fail 1: Wind Start Fail
59	Wind: Stop Fail	0: Wind Not Stop Fail 1: Wind Stop Fail
60	Wind: Initialized	0: Wind Not Initialized 1: Wind Initialized

Address	Description	Range/Meaning
61	Load1: Initialized	0: Load1 Not Initialized 1: Load1 Initialized
62	Load2: Initialized	0: Load2 Not Initialized 1: Load2 Initialized
63	CommsFail Alarm	0: No Alarm 1: CommsFail Detected for longer than CommsFail_Time (See write registers)

4.1.2.4 Input Registers

Address	Description	Range/Meaning	Units
1	Active Power - Dispatchable Generation	Total active power that should be dispatched from DG and BESS	kW
2	Active Power - Non-dispatchable Generation	Total active power available from non-dispatchable generation sources (PV and Wind)	kW
3	Active Power - Load	Total active power of the load	kW
4	Active DG Count	Number of active diesel generators	
5	Active PV Inverter Count	Number of active PV inverters	
6	Regulation Reserve - Down	Total downwards regulation reserve	kW
7	Regulation Reserve - Up	Total upwards regulation reserve	kW
8	Dispatch Alarm - Reason	If an alarm is generated by the dispatch algorithm, the reason will be listed here. The Dispatch_AlarmReason enumeration details the meaning of each value	
9	Dispatch State	Last known state of the algorithm. The Dispatch_State enumeration details the meaning of each value.	
10	Dispatch Timer	Countdown timer to the next Dispatch execution	s
11	Curtail Amount (Apply / Remove)	Total active power requested for curtailment during the last curtailment request	kW
12	Regulation Reserve Management Alarm - Reason	If an alarm is generated by the Regulation Reserve Management function, the reason will be listed here. The Regulation_Reserve_AlarmReason enumeration details the meaning of each value	
13	Regulation Reserve Management State	Last known state of the algorithm. The Regulation_Reserve_State enumeration details the meaning of each value.	
14	Regulation Reserve Management Timer	Countdown timer to the next Regulation Reserve Management execution	s
15	Blackstart Alarm - Reason	If an alarm is generated by the blackstart algorithm, the reason will be listed here. The Blackstart_AlarmReason enumeration details the meaning of each value	
16	Blackstart State	Last known state of the algorithm	
17	Blackstart Timer	Countdown timer to the next execution	s
18	Blackstart Load Priority (Small to Large)	The load that will be connected first during a blackstart (smallest load)	

Address	Description	Range/Meaning	Units
19	Blackstart DG Priority	The DG that will be connected first during a blackstart (smallest running time)	
20	DG4: Active Power (10s Average)	10s moving average of the active power	kW
21	DG4: Regulation Reserve Down	Downward regulation reserve	kW
22	DG4: Regulation Reserve Up	Upward regulation reserve	kW
23	DG4: Running Time	Total running time for the diesel generator. Used to determine the priority for Blackstart and dispatch algorithms	h
24	DG5: Active Power (10s Average)	10s moving average of the active power	kW
25	DG5: Regulation Reserve Down	Downward regulation reserve	kW
26	DG5: Regulation Reserve Up	Upward regulation reserve	kW
27	DG5: Running Time	Total running time for the diesel generator. Used to determine the priority for Blackstart and dispatch algorithms	h
28	BESS: Active Power (10s Average)	10s moving average of the active power	kW
29	BESS: Regulation Reserve Down	Downward regulation reserve	kW
30	BESS: Regulation Reserve Up	Upward regulation reserve	kW
31	BESS: Active Power Setpoint	Last Active Power Setpoint Applied to the BESS	kW
32	BESS: Charge/Discharge Cycle	Last Known State of the Charge/Discharge Cycle	
33	BESS: Min SOC	Minimum SOC setting as applied on the BESS controller. Note that this setting is read from the BESS and is used internally by the MCS to determine at which level the BESS will stop discharging.	%
34	BESS: Max SOC	Maximum SOC setting as applied on the BESS controller. Note that this setting is read from the BESS and is used internally by the MCS to determine at which level the BESS will stop charging.	%
35	BESS: Max Charge & Discharge	Maximum active power that the BESS can support. This is calculated using the equation $P_{MAX} = P_{Rated} * BESS_{cosphi}$	kW
36	PV: Active Power (10s Average)	10s moving average of the active power	kW
37	PV: Active Power Limit Setpoint	Last Active Power Limit Setpoint Applied to the PV	kW
38	Wind: Active Power (10s Average)	10s moving average of the active power	kW
39	Wind: Active Power Limit Setpoint	Last Active Power Limit Setpoint Applied to the Wind	kW
40	Load 1: Active Power (10s Average)	10s moving average of the active power	kW

Address	Description	Range/Meaning	Units
41	Load 2: Active Power (10s Average)	10s moving average of the active power	kW
42	Load 1: Active Power (5 min Snapshot)	A 5-minute snapshot of the active power of the load. Used to estimate the amount of power that will be connected during a blackstart.	kW
43	Load 2: Active Power (5 min Snapshot)	A 5-minute snapshot of the active power of the load. Used to estimate the amount of power that will be connected during a blackstart.	kW
51	Dispatch: Cycle Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
52	Dispatch: DG Min Load	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
53	Dispatch: DG Max Load	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
54	Dispatch: Min BESS SOC	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
55	Dispatch: Max BESS SOC	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
56	Frequency Control: Cycle Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
57	Frequency Control: Required Regulation Reserve Downwards	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
58	Frequency Control: Required Regulation Reserve Upwards	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
59	Blackstart: Max Retries	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
60	Blackstart: Wind Ramp Wait Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
61	Blackstart: PV Ramp Wait Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
62	DG_StartFail_Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	

Address	Description	Range/Meaning	Units
63	DG_StopFail_Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
64	BESS_StartFail_Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
65	BESS_StopFail_Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
66	BESS_CosPhi	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
67	PV_StartFail_Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
68	PV_StopFail_Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
69	Wind_StartFail_Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
70	Wind_StopFail_Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
71	Brkr_Open_Retries	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
72	Brkr_Close_Retries	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
73	Moving Average Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
74	Load_Snapshot_Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	
75	CommsFail_Time	Echo of the setting applied by the operator. Might be different if operator specifies a value outside of the allowable range.	

4.1.2.5 Enumerations

Dispatch_AlarmReason	
1	Mode 1; BESS SOC Low and Generating; Approaching Blackstart
2	Mode 2; PDG low, but no actions available to take

Dispatch_State	
	General Dispatch
1	Microgrid Not Dispatchable
2	Blocked by Regulation Reserve Management Function
3	Blocked by Blackstart Function
	Dispatch Switching
11	Starting BESS
12	Starting PV
13	Starting Wind
14	Connecting Load 1
15	Connecting Load 2
	Mode 1
21	SOC > 80 and PBESS < 0: Apply curtailment to keep PBESS = 50kW
22	SOC > 80 and PBESS >= 0: No action
23	SOC <=75 and PBESS > -200: Remove curtailment to keep PBESS Charging at 250kW
24	SOC <= 75 and PBESS <= -200 : No action
25	SOC <= 30 and PBESS > 0: Alarm, low SOC approaching Blackstart
	Mode 2
41	Start a DG
42	Stop a DG
43	Ramp BESS to zero (BESS Discharging)
44	Ramp BESS to zero (BESS Charging)
45	PDG low, adjust BESS setpoint
46	PDG low, apply curtailment
47	PDG low, no action
48	PDG high, remove curtailment
49	PDG high, adjust BESS setpoint
50	PDG high, no action
51	300 > PDG > 250, curtail enabled and PBESS >= -450kW – remove curtailment
52	300 > PDG > 250, no action

Regulation_Reserve_AlarmReason	
1	RRd Low, but no actions available
2	RRu Low, but no actions available

Regulation_Reserve_State	
Mode 1	
21	Initiate Blackstart
22	RRu low, Remove Curtailment
23	RRd low, Apply Curtailment
Mode 2	
11	Switching BESS to VSG Mode
12	RRd low, Adjusting BESS P_sp
13	RRd low, Apply curtailment
14	RRd low, No action
15	RRu low, Remove curtailment
16	RRu low, Adjust BESS P_sp
17	RRu low. Start second DG
18	RRu low, No action

Blackstart_AlarmReason	
1	Max retries exceeded
2	Could not open all breakers, Blackstart not possible
3	Blackstart Priority Autoswitch Disabled, Blackstart Priority DG, Blackstart DG not possible
4	Blackstart Priority Autoswitch Disabled, Blackstart Priority BESS, Blackstart BESS not possible
5	Blackstart not Possible with BESS or DG
6	Blackstart not Possible, no loads available

Blackstart_State	
Common States (Mode 1 and Mode 2)	
1	Disconnect all DER and loads
2	Breakers Open, Checking Blackstart Feasability
31	Connect the smaller load
311	Connect the bigger load (smaller load did not connect or is not available)
32	Start the PV
33	Start the Wind
34	Connect the bigger load (if not already connected)
36	Blackstart Complete
Mode 1 Specific	
21	Start the BESS (VSG Off-grid)
Mode 2 Specific	
11	Start the first DG
12	Start the BESS (VSG On-grid)
13	Start the second DG (if needed and available)
35	Switch the BESS to grid-connected mode and adjust setpoint

BESS_ChargeCycle	
1	Charge Only
2	Charge/Discharge
3	Discharge Only

5 REFERENCES

[1] CAT, "EMCP 4 Modbus Registers - 4.2 Prod Software".

[2] Sungrow, "Sungrow SC500TL/SC630TL Power conversion System (PCS) – Operational Manual, SC500-V31_630TL_V11-OEN-Ver13-201906, Version 1.3.".

[3] Sungrow, "SG110CX PV Grid-Connected Inverter User Manual, SG110CX-UEN-Ver14-201912".

[4] E. W. T. BV, "Power Curtailment Functional Description, Document Code: S-1000810.docx," 2016.

[5] Sungrow, "Communication Protocol of PV Grid-Connected String Inverters, V1.1.30".

APPENDICES: DETAILED MCS CONTROL SEQUENCES

DER Dispatch

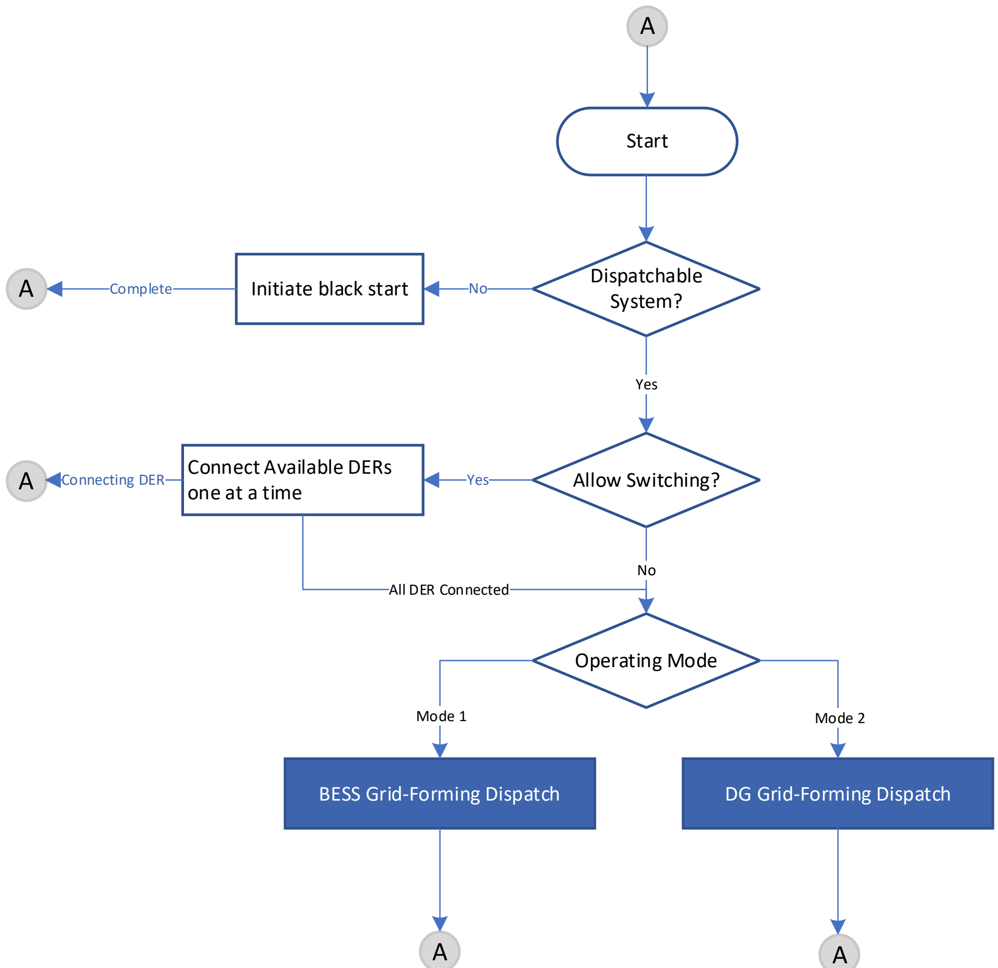

Figure 33- Dispatch Function (Overview)

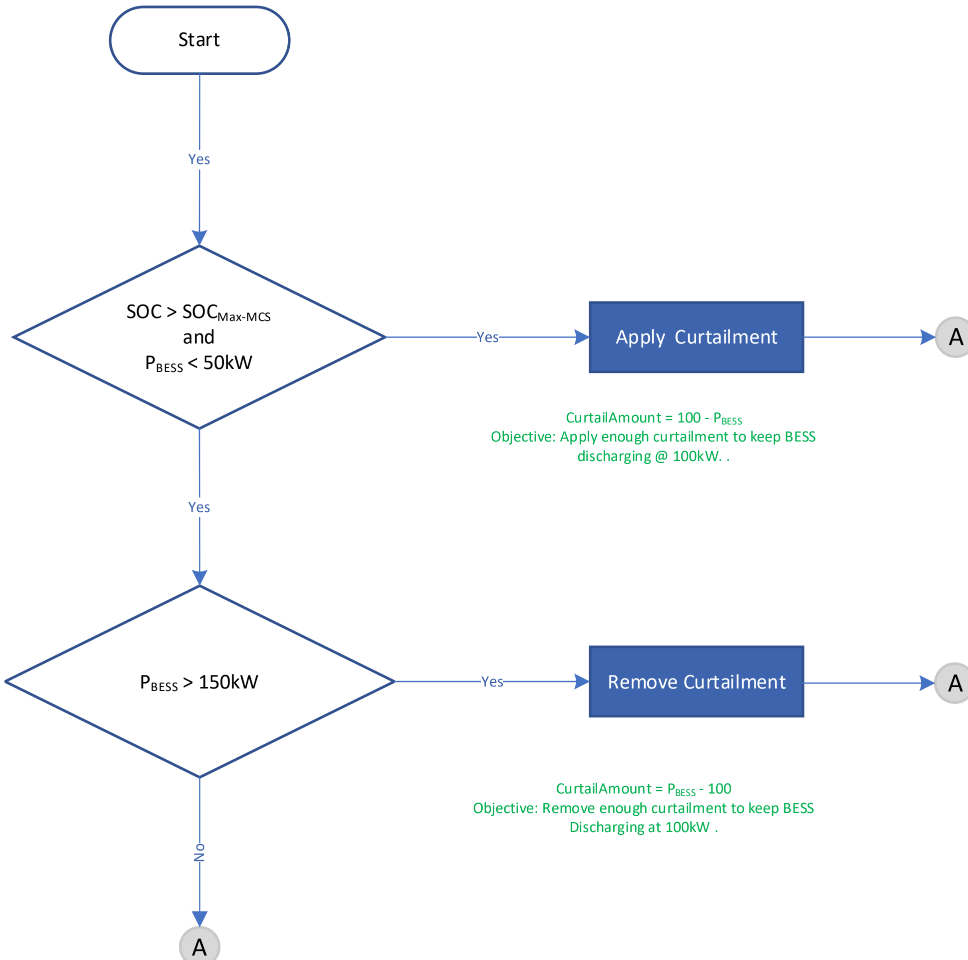

Figure 34- Dispatch Function (Mode 1)

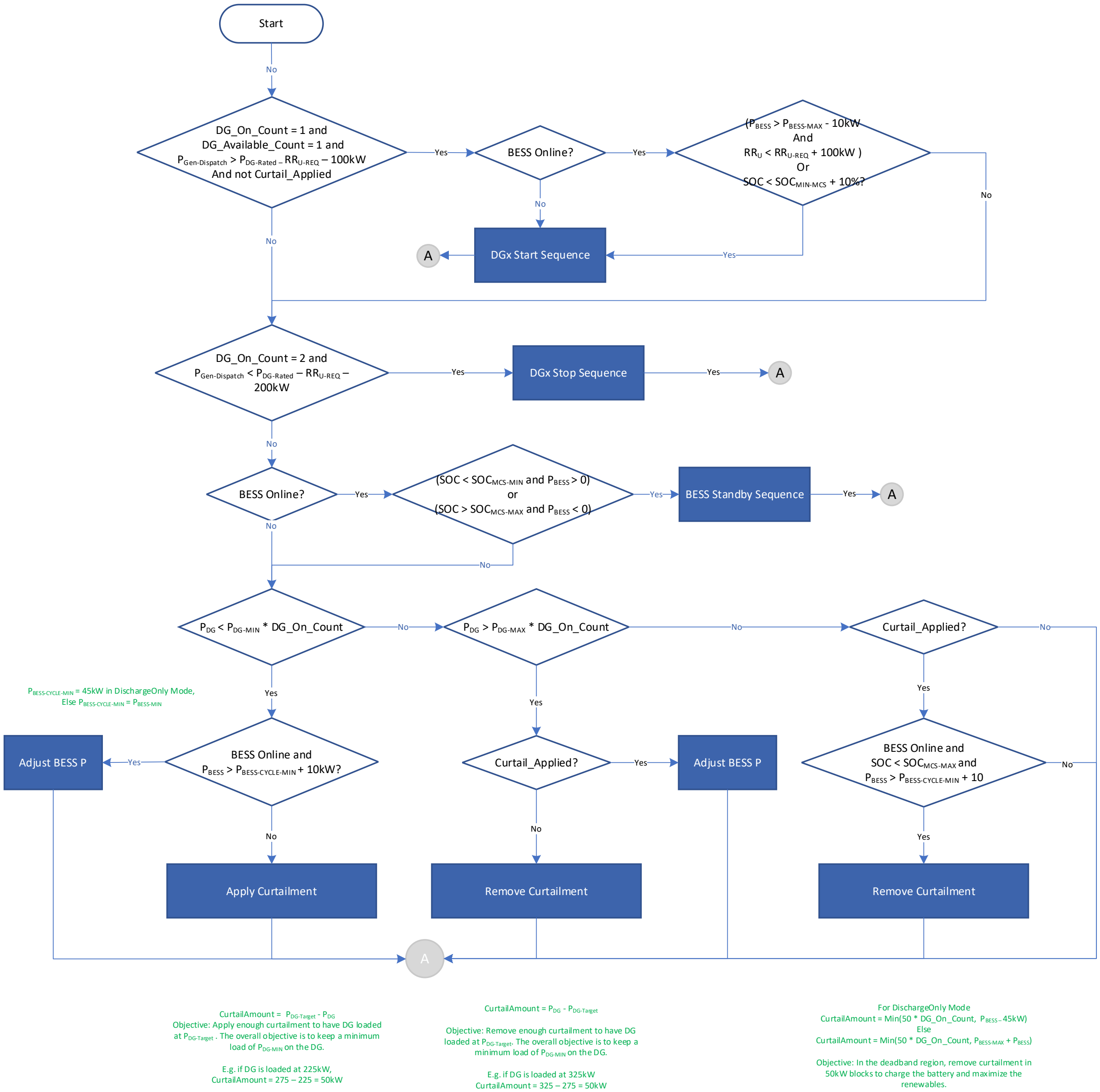

Figure 35- Dispatch Function (Mode 2)

Regulation Reserve Management

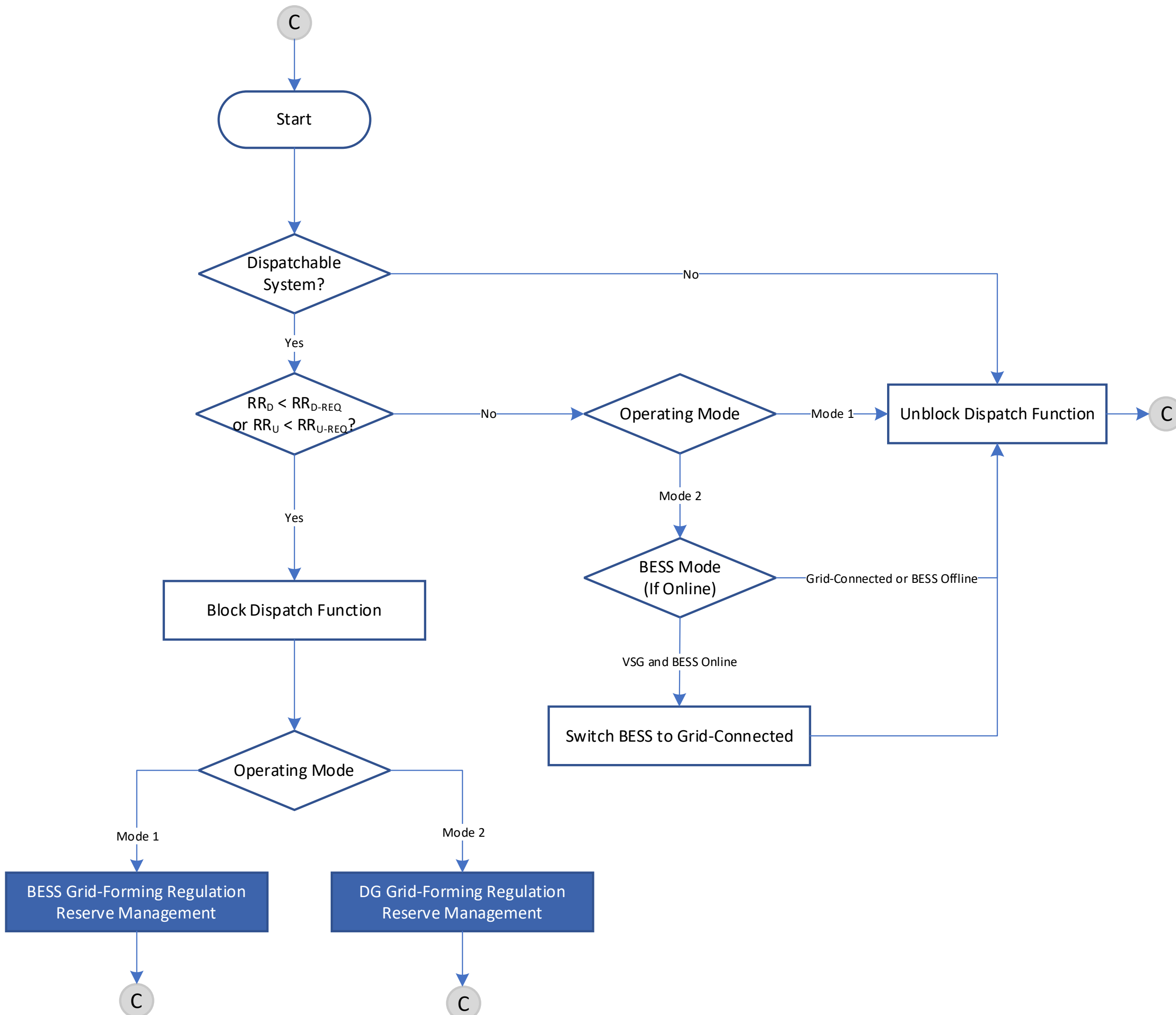

Figure 36- Regulation Reserve Management Function (Overview)

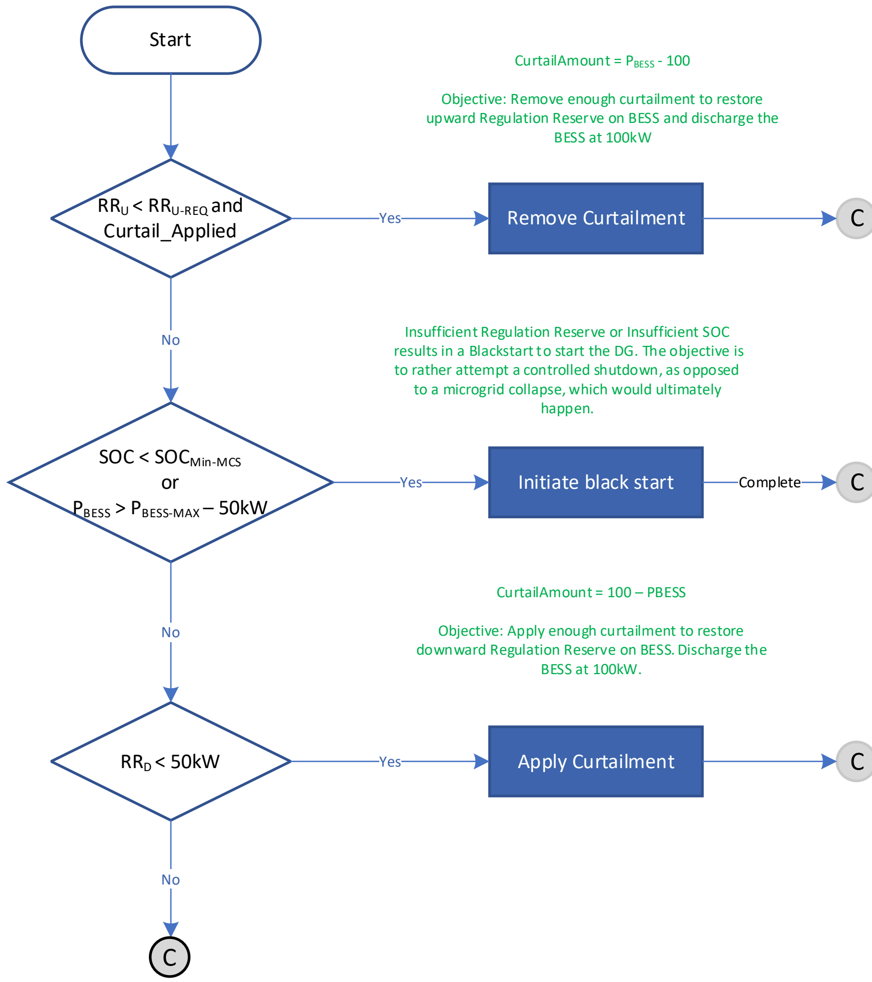

Figure 37- Regulation Reserve Management Function (Mode 1)

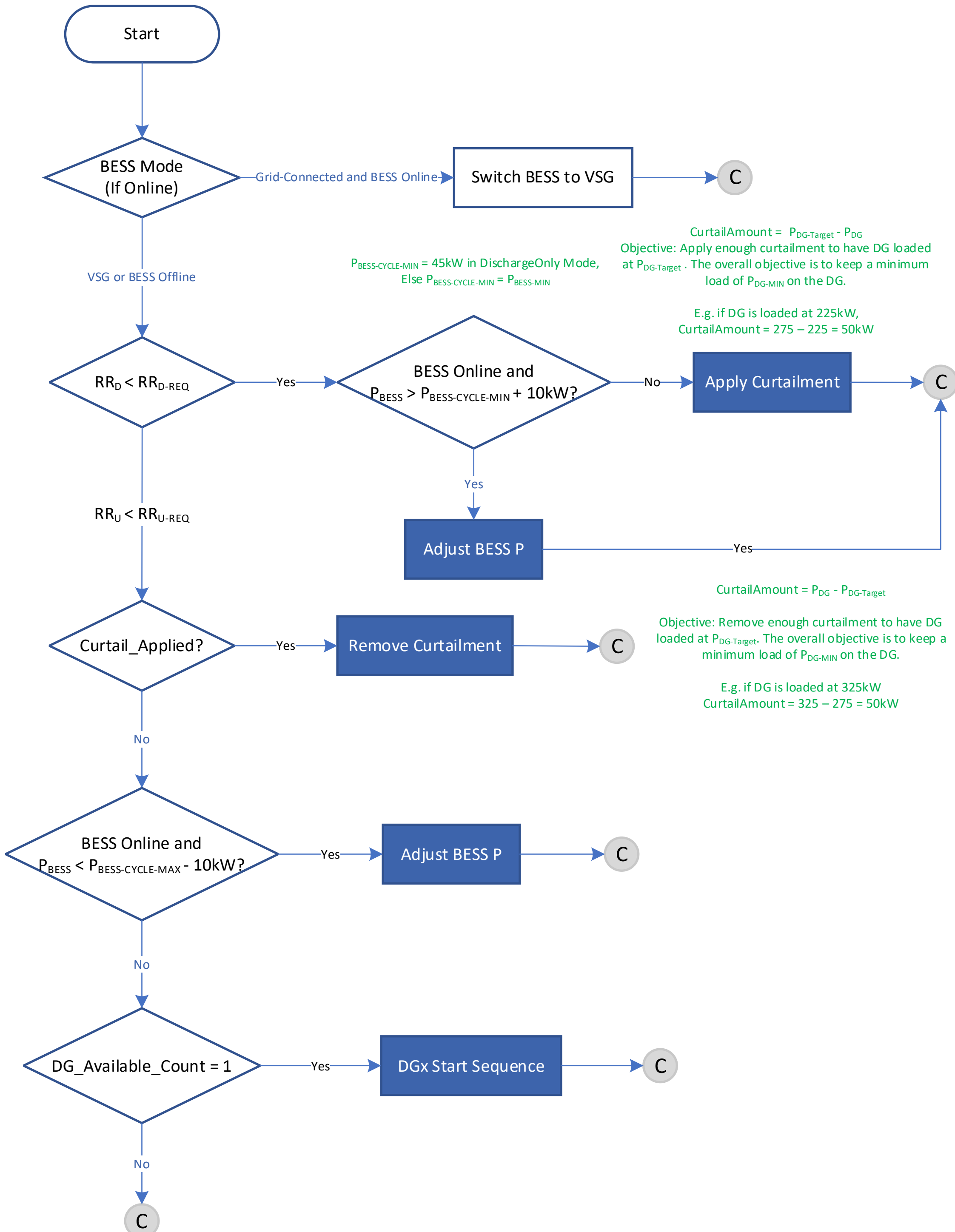

Figure 38- Regulation Reserve Management Function (Mode 2)

Black Start

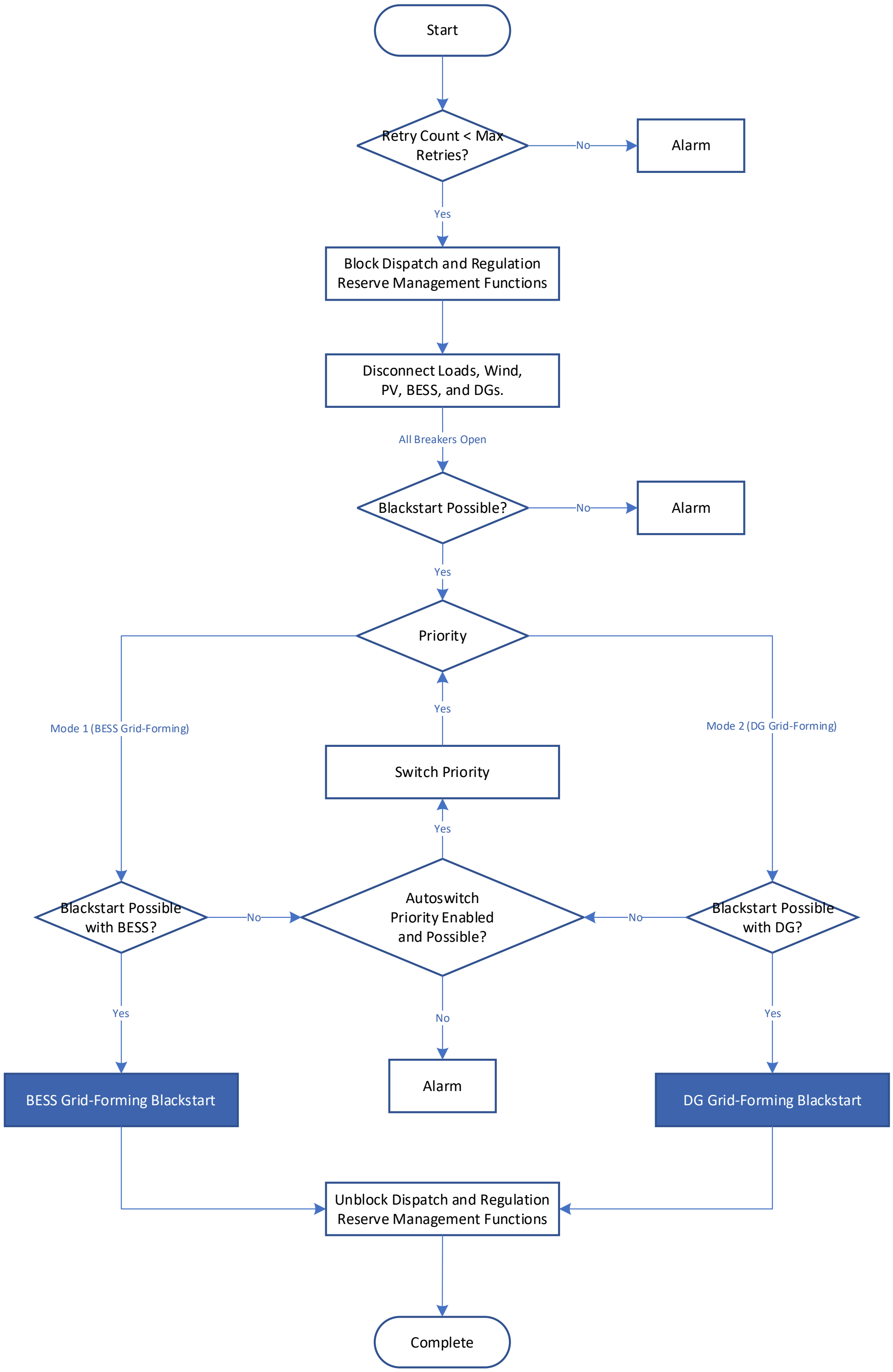

Figure 39- Blackstart Function (Overview)

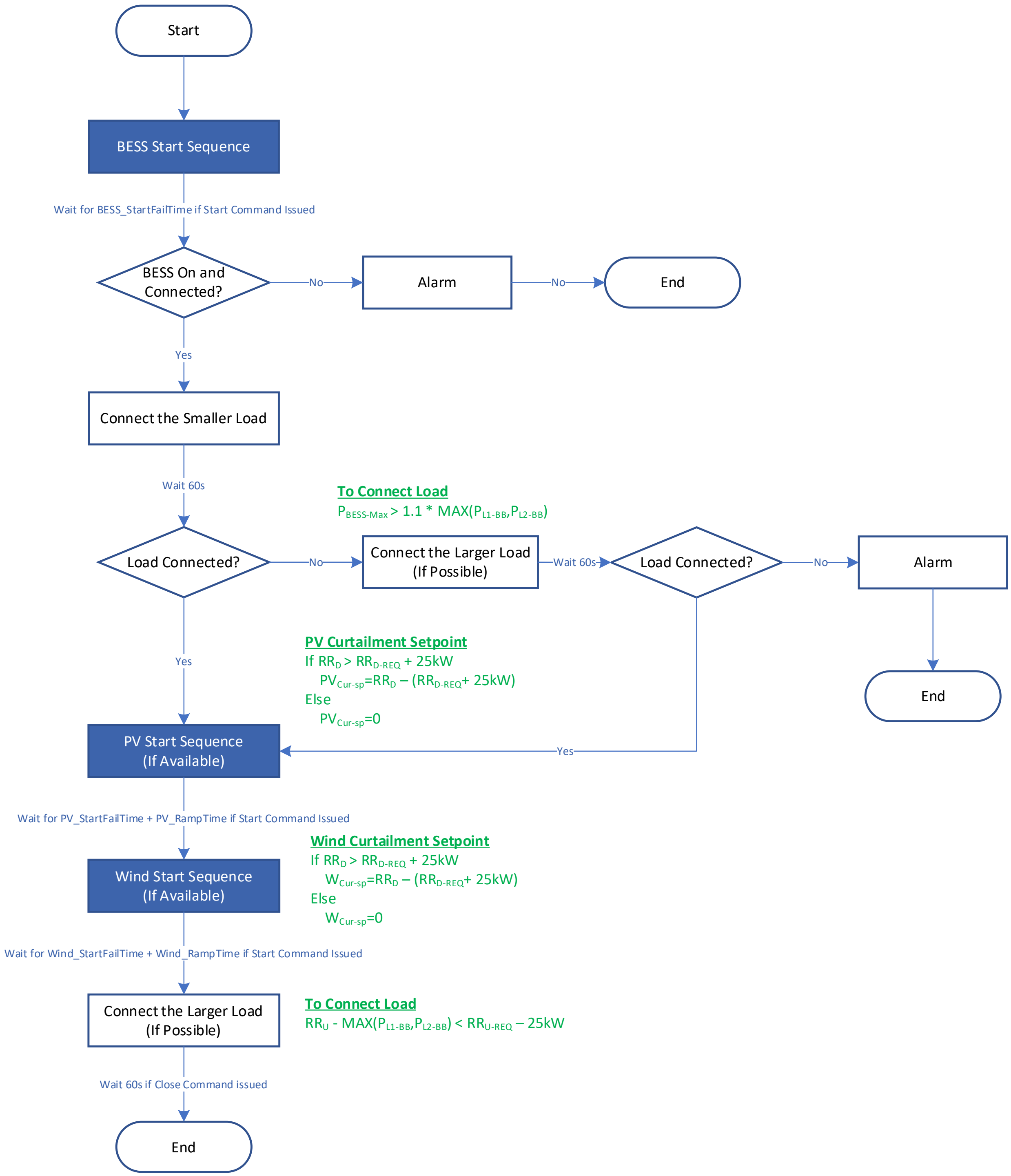

Figure 40- Blackstart Function (Mode 1)

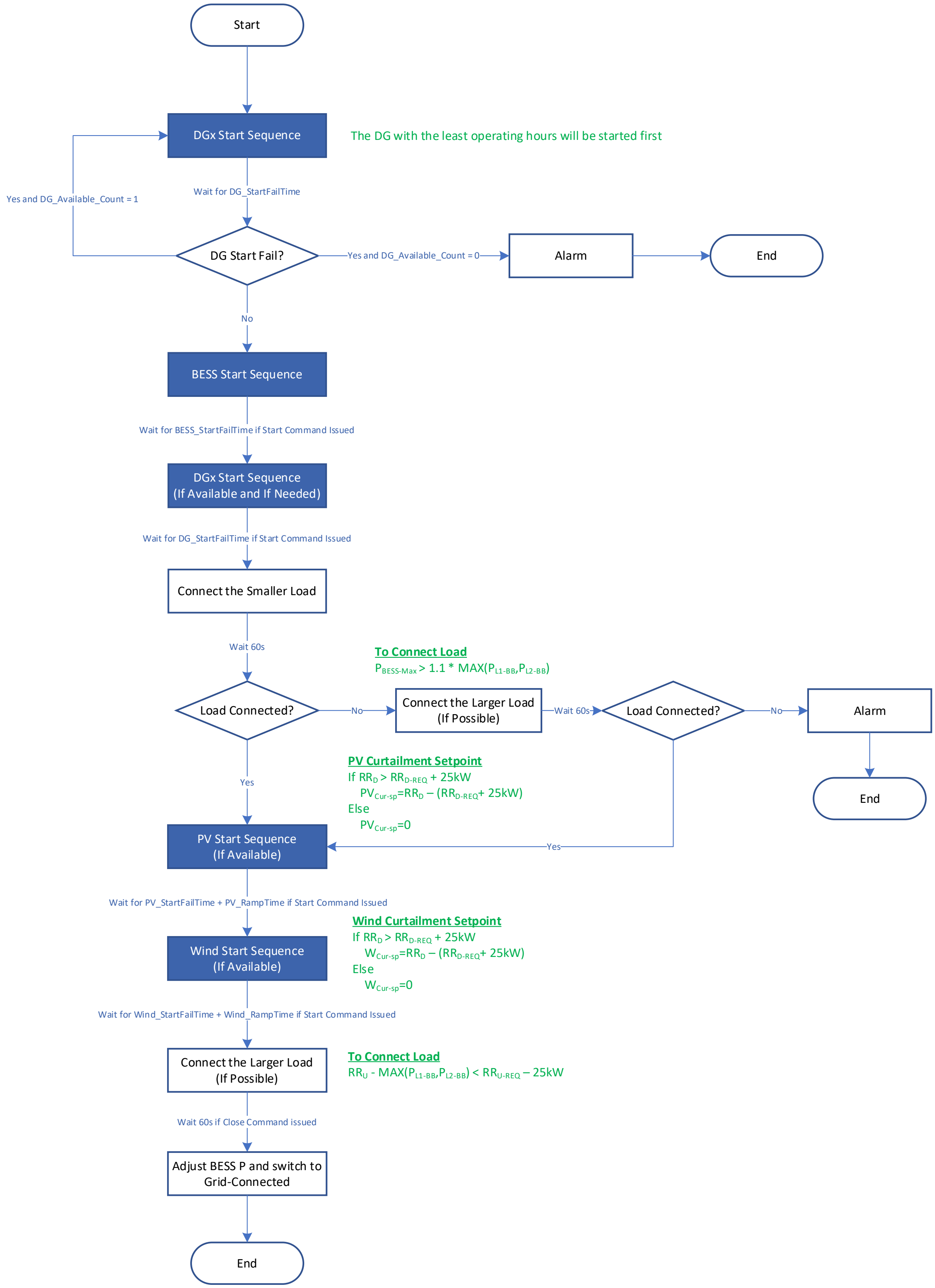

Figure 41- Blackstart Function (Mode 2)

Curtailment Function

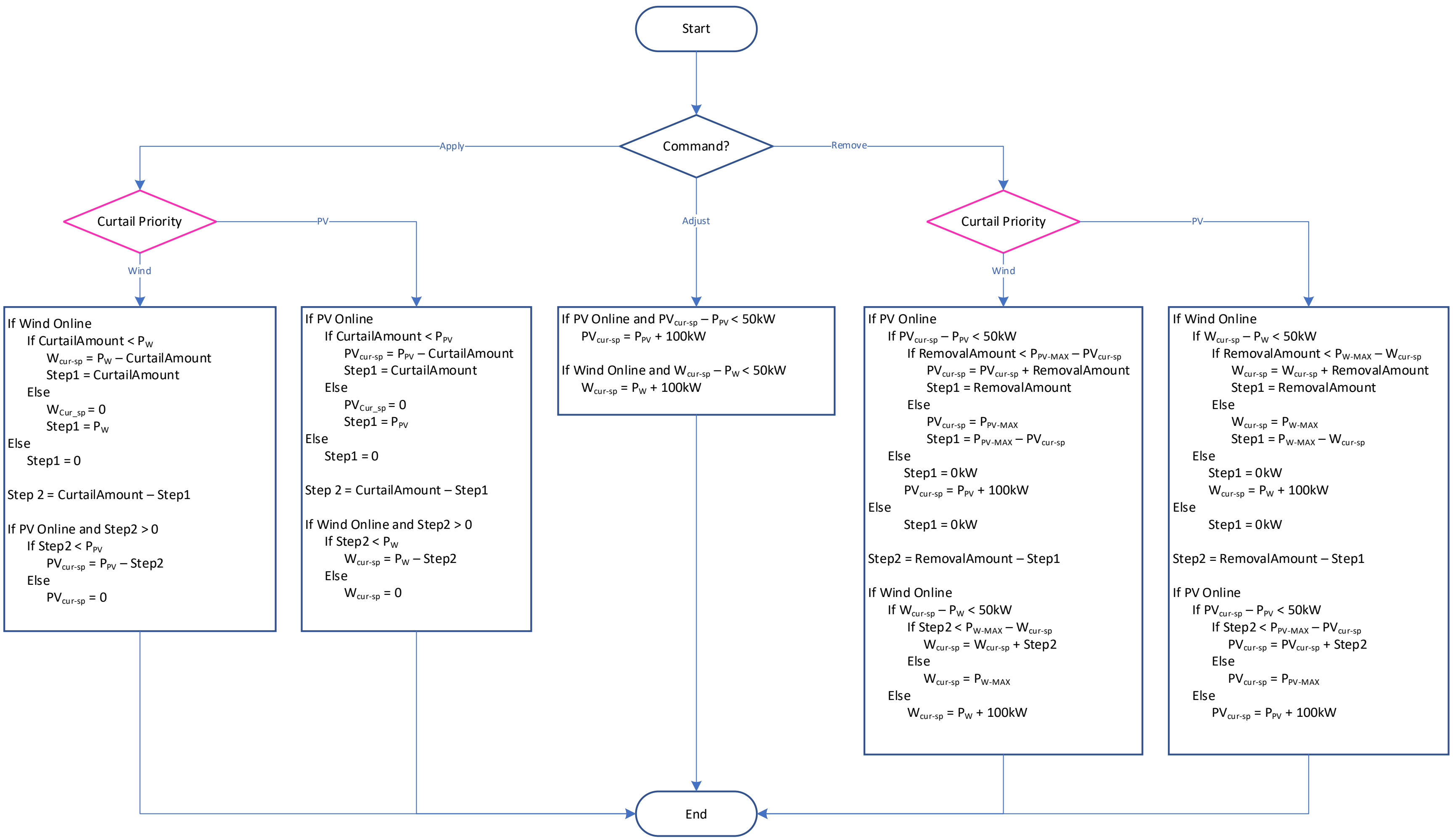

Figure 42- Curtailment Function

BESS SOC Management Function

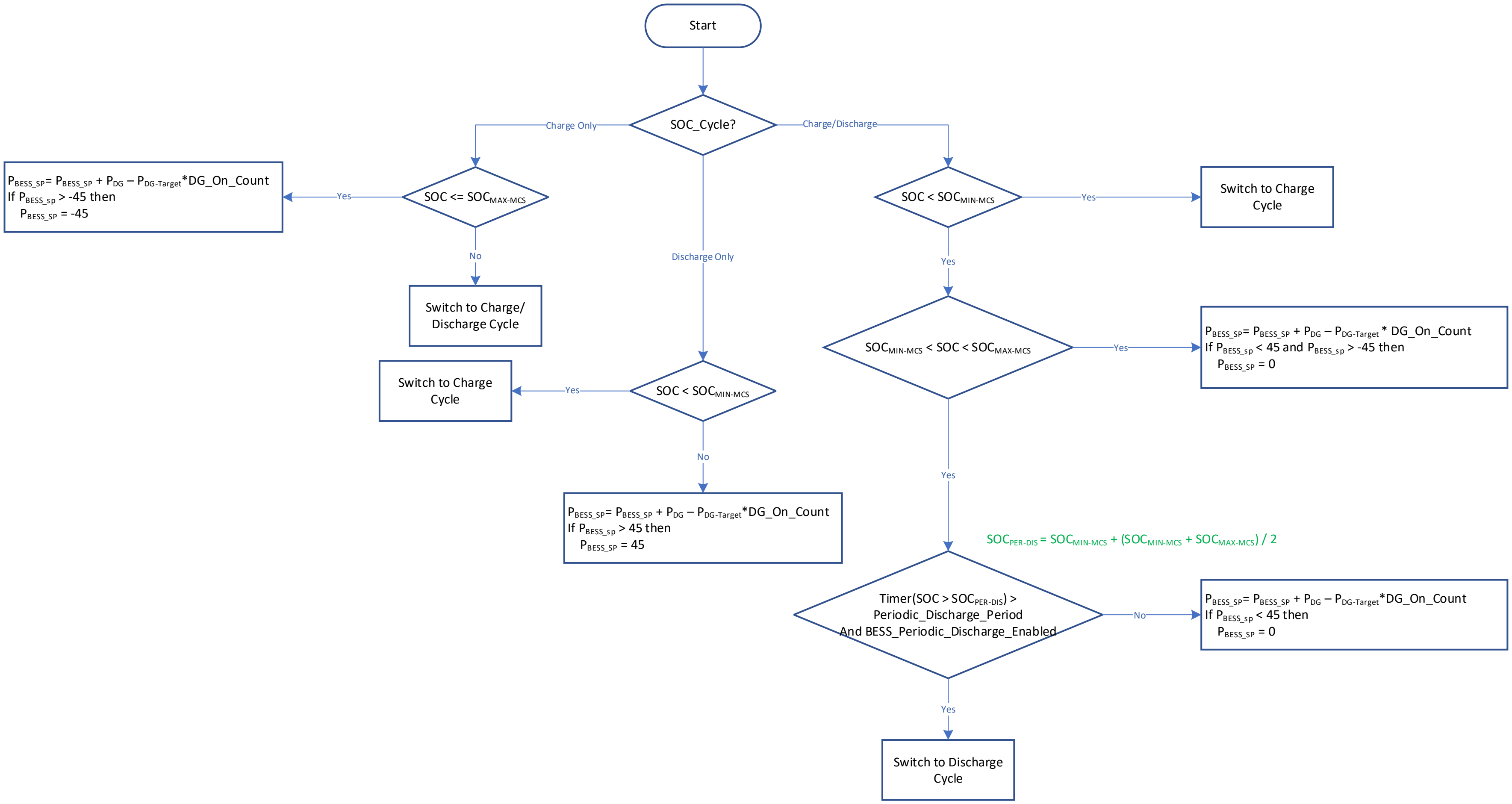

Figure 43- BESS SOC Management Function

BESS Unloading Function

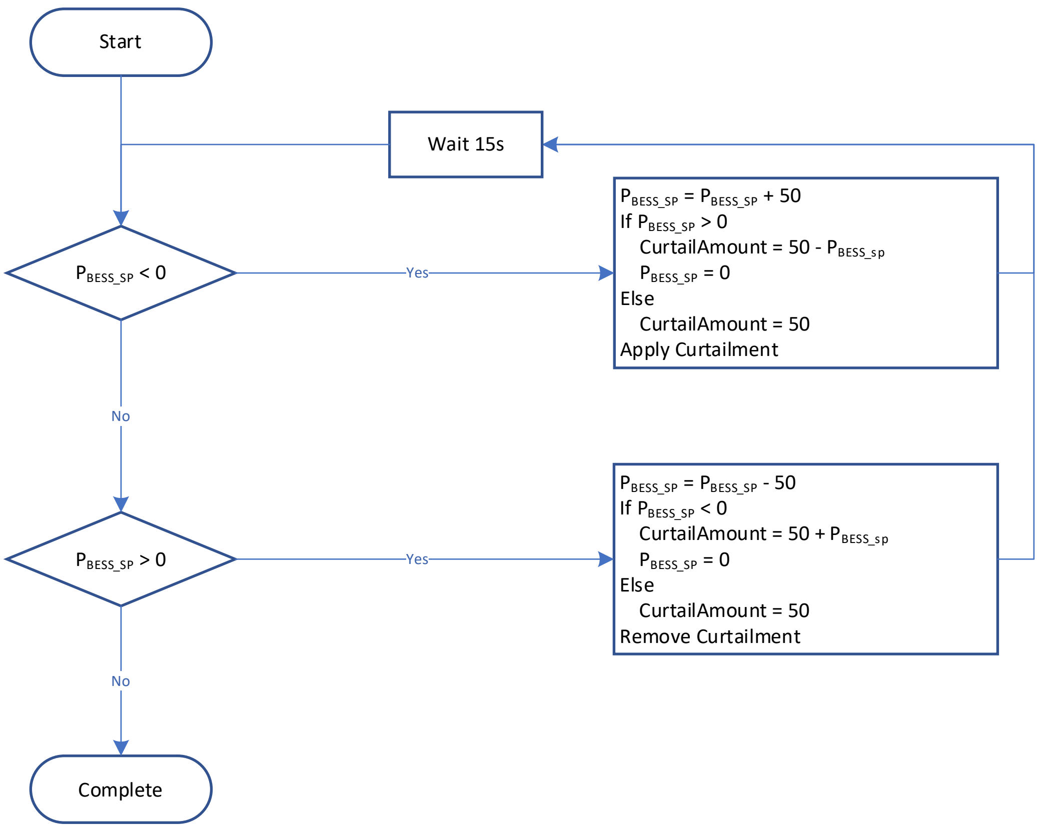

Figure 44- BESS Unloading Function