BESS Site Acceptance & Performance Test Guidelines

Project Name:
WAPA 2 BESS

Customer:
US VIRGIN ISLANDS WATER AND POWER AUTHORITY

Note: This is a draft versions of the test guidelines.

This document will be finalized once all equipment parameters are validated and fuctional specifications have been agreed to wtih WAPA and validated by hardwware engineering team

Table of Contents

1. Master Site Acceptance Test

This section outlines the overall Site Acceptance Test (SAT) process for the Wärtsilä Engine+ solution for the WAPA 2 project.

The Master SAT process focuses on communication, control, performance and functional aspects of the plant, including the following components:

- Network communication
- GridSolv containers
- Battery Energy Storage System (BESS) control and performance
- Engine+ GEMS control and automation

1.1 Network Site Acceptance Test

The Wärtsilä engineer verifies that the plant network devices are installed, configured, and communicating correctly.

The Network SAT is described in section 2.

1.2 GridSolv Site Acceptance Test

The Wärtsilä engineer verifies that the Wärtsilä GridSolv battery containers are installed, configured, and functioning correctly.

The GridSolv SAT is described in section 3.

1.3 BESS Plant Control and Performance Site Acceptance Test

The Wärtsilä engineer verifies that the BESS equipment is installed, configured, and functioning correctly. The BESS equipment includes the batteries, power conversion systems (PCSs), and other balance of plant equipment such as meters and switchgears.

The Wärtsilä engineer also verifies the control and performance of the BESS by GEMS, including the BESS capacity, PCS response time, and functional operation of the plant.

The BESS Plant Conrol and Performance SAT section 4.

1.4 ESS Capacity Site Acceptance Test

The ESS Capacity SAT is described in section 5.

1.5 Enginge+ GEMS Control and Automation SAT

The Wärtsilä engineer verifies the communication and control of power plants and ancillary hardware under GEMS scope.

The Wärtsilä engineer also verifies the control and performance of the GEMS Automation functionality, including primary control, secondary control, tertiary control, and forecasting functions. The Engine+ GEMS Control and Automation SAT is described in document "Exhibit A13b_Wartisla_ Engine+_ GEMS_SAT_Template_v4".

1.6 Post-Commissioning Checklist

Before leaving site, the Wärtsilä engineer verifies a set of GEMS PPC settings to ensure that it is in full production state.

Please refer to GEMS Post-Commissioning Checklist for details.

2. Network Site Acceptance Test

This section describes the Site Acceptance Test (SAT) process for the Wärtsilä network for the [Name] project.

Prerequisite

The commissioning engineer who is in charge of the Device Communication SAT understands <Wartsila ESS Standard Network Design> and has basic knowledge about the TCP/IP networking, Ethernet LAN Switch, IP Routing (only need to know static route), firewall, NAT and IPsec VPN.

Background

The device communication network could be divided into two parts: core and edge. The core network is located in the GEMS PPC rack, the edge network is located in GridSolv containers, switchgear cabinet or other project specific possible installation points.

The core network is configured and installed by the third party instead of Wartsila itself. The edge network is also configured by the same third party, but it has to be installed on site later. The third party should do the FAT before shipping the GEMS PPC rack and other network devices to the specific project. In theory, all the internal device communications should work well as long as the edge network is installed correctly on site.

The following factors might cause a couple of problems in the internal device communications:

1. *The third party and Wartsila don't have a thorough and same understanding about our network design or related network design documents*
2. *The standard network design is a new design to us, we haven't done the verification test by ourselves in our lab during the design phase*
3. *There might be a couple of installation problems in the edge network.*

However, all the communications to the outside network need to be configured and verified on site during the pre-commissioning phase on site. The commissioning engineer would take the responsibility to configure them.

As a commissioning engineer, you need to know how to resolve some device communication problems caused by the wrong installation in the edge network.

The accompanying worksheet template must also be customized:

Customizable Item	Description
TBD-01	Customer Public IP
TBD-02	GEMS Public IP
TBD-03	Ingress Signaling RTU Public IP
TBD-04	GEMS SCADA Port
TBD-05	Ingress Signaling Port
TBD-06	Wartsila IP Range for ingress traffic
TBD-07	GEMS Fleet Director IP
TBD-08	Egress Signaling Server Public IP
TBD-09	Egress Signaling Port
TBD-10	NAT IP for PPC1 AMT
TBD-11	NAT IP for PPC2 AMT
TBD-12	NAT IP for PPC VIP
TBD-13	NAT IP for PPC1
TBD-14	NAT IP for PPC2
TBD-15	Wartsila IPSec VPN public IP address
TBD-16	IPSec VPN Pre-shared Key
TBD-17	BPP network NAT rules and Firewall rules

There are multiple tab pages in the SAT spreadsheet, each page has a different kind of test case.

2.1 Device Physical Check

Device physical check is the first step of network SAT. The result column in this table has three options: Good, Not Powerup and Not Found.

Device Physical Check					
Device	**Pcs**	**Tag Name**	**Location**	**Result**	**Remarks**
Instruction: Check whether all network devices are installed into the correct place, especially for the EDS-408 and EDR-810.					
Network Equipments Verification					
FG-80E-1	1	AF11	GEMS PPC Rack		
FG-80E-2	1	AF12	GEMS PPC Rack		
FS-224E-1	1	AF21	GEMS PPC Rack		
FS-224E-2	1	AF22	GEMS PPC Rack		
EDS-608-1	1	AF31	GEMS PPC Rack		
EDS-608-2	1	AF32	GEMS PPC Rack		
EDS-408-1	1	?	GridSolv BSG01		
EDS-408-2	1	?	GridSolv BSG02		
...					
EDS-408-N	1	?	GridSolv BSG0N		N is the number of GridSolv containers
EDS-408-N+1	1	?	Switchgear Cabinet		
EDR-810-1	1	?	GridSolv BSG01		
EDR-810-2	1	?	GridSolv BSG02		
...					
EDR-810-N	1	?	GridSolv BSG0N		
EDR-810-N+1	1	?	Switchgear Cabinet		

2.2 Port and Link Check

Port and link check is the second step of network SAT. This table is also a part of our FAT proposal to VEO. If it is not possible to simply copy it from the FAT directly, this table needs to be copied from the project layout document provided by VEO.

The result column in this table has three options: Good, No Cable and Light is Off. Light is Off means that the status light of this ethernet port is off, it’s usually caused by a cable issue or peer device isn’t powered up.

Port and Link Check

Cable Name	Type	Source	S Tag	S Port	Destination	D Tag	D Port	Result	Remarks
Instruction: This table is copied from VEO's drawing, hope we can use the same table and don't need to copy it									
Internal Network Physcial Connection Verification									
7A01	CAT5E	FS-224E-1	AF21	15	GEMS PPC 1	CWS905	ETH1		
7A04	CAT5E	FS-224E-1	AF21	12	GEMS HMI	CWS931	1		
7A05	CAT5E	FS-224E-1	AF21	16	GEMS PPC 2	CWS906	ETH1		
7A07	CAT5E	FS-224E-2	AF22	15	GEMS PPC 1	CWS905	ETH2		
7A09	CAT5E	FS-224E-2	AF22	16	GEMS PPC 2	CWS906	ETH2		
7A12	CAT5E	FS-224E-1	AF21	11	GPS NTP	CWT901	NA		
7A13	CAT5E	FS-224E-1	AF21	17	FS-224E-2	AF22	17		
7A14	CAT5E	FS-224E-1	AF21	18	FS-224E-2	AF22	18		
7A15	FO	FS-224E-1	AF21	26	FG-80E-2	AF12	WAN1		
7A16	FO	FS-224E-2	AF22	25	FG-80E-1	AF11	WAN2		
7A17	FO	FS-224E-1	AF21	25	FG-80E-1	AF11	WAN1		
7A18	FO	FS-224E-2	AF22	26	FG-80E-2	AF12	WAN2		
7A19	CAT5E	FG-80E-1	AF11	HA	FG-80E-2	AF12	HA		
7A21	CAT5E	FG-80E-1	AF11	12	EDS-608-1	AF31	3		
7A24	CAT5E	FG-80E-2	AF12	12	EDS-608-2	AF32	3		
7A31	FO	EDS-608-1	AF31	7	EDS-608-2	AF32	7		
59001	FO	EDS-608-1	AF31	6	EDS-408-5	SWGC01	?		
59002	FO	EDS-608-2	AF32	6	EDS-408-5	SWGC01	?		
59003	FO	EDS-608-1	AF31	5	EDS-408-1	BEP0101	?		
59007	FO	EDS-608-2	AF32	5	EDS-408-4	BEP0401	?		
External Network Physcial Connection Verification									
?		FG-80E-1	AF11		Customer Switch		?		
?		FG-80E-2	AF12		Customer Switch		?		

2.3 IP Access

In the "IP Access" tab page, all network devices and servers in the GEMS PPC rack are listed here. The laptop connected to the onsite port or a PPC should be able to ping all of them.

2.4 TCP Access

The "TCP Access" page focus on the external communication test. Before the test, we need to make sure the IPsec VPN and firewall rules setup successfully.

2.5 Redundancy

The precondition of the redundancy test is that there is no disconnected alarm on the GEMS HMI. Please follow the test steps of each test case.

3. GridSolv Site Acceptance Test

This section describes the Site Acceptance Test (SAT) process for the Wärtsilä GridSolv container for the [Name] project.

The accompanying worksheet template must also be customized

Customizable Item	*Comments*
Container Type	*Usually one project has the same container type.*
Number of Doors	*Usually one project has the same number of doors.*
Number of ESS Unit	*The number of ESS Unit is equal to the number of DC bus in the container. Please get the correct info from the section "GridSolv Configuration" in the function specification of this project. There might be two different number of ESS Unit.*

Number of Power Supplies	*Usually one project has the same number of power supplies. And it's decided by the battery type. Samsung battery has 9 power supplies, CATL battery only has 3 power supplies.*
Number of GridSolv Containers	*This is an obvious thing for different project. Each container requires its own 3 sheets in our SAT worksheet.*

Customize the GridSolv1 BOP, FSS, and HVAC tabs following the above table. Review all highlighted sections and enter the project-specific values. Then, in the Configuration tab, enter the project name and number of GridSolvs, and click the button to automatically generate copies of the tabs for the number of specified GridSolvs. Double check that the auto-generated tabs and Summary page are correct.

3.1 Equipment Installation Check

All equipment installation checks must pass before any power up and control tests can be conducted.

3.1.1 GridSolv Installation Check

Prior to commissioning, Wärtsilä engineer verifies that Wärtsilä GridSolv battery containers are installed and configured correctly by following GridSolv on-site commissioning check list.

Verify the following:

- The exterior of each GridSolv is free of any signs of damage and the interior is free of any signs of leaks or water intrusion.
- Each GridSolv is sitting flat on the concrete pad with little to no gap. Gaps are sealed with Caulking.
- All container grounding attachments are properly torqued, and have the correct size conductors (*per GridSolv Installation Manual section 7.1*)
- The DC Combiner Cabinet (DCC) has only one lug per position. Verify the torque level and torque marks are present. (*7.2*)
- All cable entries are sealed with fire proof calking or foam. (7.2)
- Each door can be opened/closed, locked/unlocked.
- All DC cables have been tested according to the Gridsolv Installation Manual specifications
- All compartments are dry and free of dust, debris and rust.
- If mounted on Piers / Pylons, verify that the container is level on all sides, (use of a level)
- If mounted on a concrete pad, GridSolv is sitting flat on the concrete pad with little to no gap and gaps are sealed with high strength grout, or Caulking.

3.1.2 Battery Installation Check

Wärtsilä or vendor engineer verifies all battery modules are installed inside GridSolv containers according to design by following vendor provided battery commissioning check list.

Special attention to the BMS heartbeat timeout is configured correctly according to GEMS requirement.

Verify the following:

- Each of the module retention screws are torqued according to the manufacturer's requirements and torque marks are present.
- Rack and module voltage levels are within the expected range per the manufacturer's requirements
- Each of the bus bar connections are torqued according to the manufacturer's requirements and torque marks are present.
- All module and Rack control unit terminal caps are securely placed
- All low voltage (24V) and canbus or TCP/IP communication cables are installed and properly connected.
- All Module Fans turn on when fan power supplies are energized
- Troubleshoot any communication issues on the can bus circuits (if necessary)

3.2 GridSolv Container Verification

For each GridSolv container, Wärtsilä engineers need to execute all the SAT test cases one by one and record the test results in the SAT worksheet or SQAD system. For some test cases, Wärtsilä engineers need to work with the vendor engineer.

3.2.1 Container Balance of Plant Verification

The test cases for the balance of plant equipment are on the "GridSolv *X* BOP" sheet (where X is the container sequence number).

3.2.1.1 Container Configuration Verification

(Review and update the default values and configurations in the worksheet.)

The Wärtsilä engineer will verify the container configurations.

Most of customizable items belong to container configurations. Wärtsilä engineer could check all the container configurations via GEMS HMI. In case of GEMS controller can't reach out a container or we want to troubleshoot an issue, Wärtsilä engineer could use GridSolv-Remote via container local network to check the configurations.

During the SAT, if we find any unexpected configuration, please follow this table to resolve the problems.

Configuration	Resolve Method	Comments
PLC Name	PLC Name is set by the FAT. If the PLC Name don't match the label name of the container. There are two possible reasons. The first reason is that FAT set a wrong PLC name, the second is that this container might have the wrong IP address. How to distinguish these two reasons? Using GridSolv-Remote to read the PLC Name: 1) if this name is correct and not equal to the name from HMI, this container has a wrong IP address, please follow the instruction in < Wärtsilä GEMS Network Troubleshooting> to resolve this issue; 2) if this name is equal to the name from HMI and a wrong name, correct it via HMI.	
Watchdog Timeout	Using GridSolv-Remote to set a correct value.	

Heartbeat Interval	Using GridSolv-Remote to set a correct value.	
Scan Rate	Using GridSolv-Remote to set a correct value.	
ESS Units Count	Using GridSolv-Remote to set a correct value.	
Container Type	Using GridSolv-Remote to set a correct value.	
Container Doors count	Using GridSolv-Remote to set a correct value.	
FACP Supervisory Alarm	Using GEMS HMI to set a correct value.	
FACP Trouble Alarm	Using GEMS HMI to set a correct value.	
FSS Enabled	Using GEMS HMI to set a correct value.	
Power Supplies Count	Using GridSolv-Remote to set a correct value.	

3.2.1.2 Container Status Verification

(Make sure the number of power supplies is correct in the BOP tab of the worksheet.)

A pair of Wärtsilä hardware engineers will verify the container status. A Wärtsilä hardware engineer is in charge of triggering part of container warnings in the container, while another Wärtsilä engineer records the test result in the worksheet. Ideally, a pair of walkie talkies are available to complete these test cases.

3.2.1.3 Container Command Verification

A pair of Wärtsilä hardware engineers will verify the container status. A Wärtsilä hardware engineer is in charge of checking the PLC status in the container, while another Wärtsilä engineer records the test result in the worksheet. Ideally, a pair of walkie talkies are available to complete these test cases.

3.2.1.4 Container Temperature Verification

A pair of Wärtsilä hardware engineers will verify the container temperature readings. A Wärtsilä hardware engineer is in charge of executing these test cases in the container, while another Wärtsilä engineer records the test result in the worksheet. Ideally, a pair of walkie talkies are available to complete these test cases.

3.2.1.5 Container Humidity Verification

A pair of Wärtsilä hardware engineers will verify the container humidity readings. A Wärtsilä hardware engineer is in charge of executing these test cases in the container, while another Wärtsilä engineer records the test result in the worksheet. Ideally, a pair of walkie talkies are available to complete these test cases.

3.2.1.6 Container E-Stop Verification

A pair of Wärtsilä hardware engineers will verify the container emergency stop functionality. A Wärtsilä hardware engineer is in charge of executing these test cases in the container, while another Wärtsilä engineer sends the E-stop command and records the test result in the worksheet. Ideally, a pair of walkie talkies are available to complete these test cases.

The Wärtsilä engineer will also verify that when a GridSolv emergency stop is activated, GEMS locks the ESS unit(s) associated with that GridSolv.

3.2.1.7 Container Door Verification

(Make sure the number of doors is correct in the BOP tab of the worksheet.)

A pair of Wärtsilä hardware engineers will verify the container door safety system. A Wärtsilä hardware engineer is in charge of executing these test cases in the container, while another Wärtsilä engineer sends the reset command and records the test result in the worksheet. Ideally, a pair of walkie talkies are available to complete these test cases.

The Wärtsilä engineer will also verify that when a GridSolv raises a critical fault on the door safety system, GEMS locks the ESS unit(s) associated with that GridSolv.

3.2.1.8 Container ESS Unit Safety System Verification

(Make sure the number of ESS Unit Safety System tests is correct in the BOP tab and Summary page of the worksheet.)

A pair of Wärtsilä hardware engineers will verify the ESS unit safety system. A Wärtsilä hardware engineer is in charge of executing these test cases in the container, while another Wärtsilä engineer sends the ESS unit safety system command and records the test result in the worksheet. Ideally, a pair of walkie talkies are available to complete these test cases.

The Wärtsilä engineer will also verify that when a GridSolv raises a critical fault on the ESS unit safety system, GEMS locks the ESS unit(s) associated with that GridSolv.

3.2.2 Container Fire Safety System Verification

IMPORTANT: ONLY AFTER THE COMMISSIONING SHOULD THE FACP RELEASING HARDWARE BE INSTALLED.

A pair of Wärtsilä hardware engineers and the fire safety system technician will verify the fire safety system. A Wärtsilä hardware engineer will work with the fire safety system technician in the container, while another Wärtsilä engineer sends the fire safety system command and records the test result in the worksheet. Ideally, a pair of walkie talkies are available to complete these test cases.

(If a critical safety system fault locks down entire site)
The Wärtsilä engineer will also verify that when any GridSolv raises a critical fault on the fire safety system, GEMS locks the entire Site ESS.

(If a critical safety system fault locks respective ESS units)
The Wärtsilä engineer will also verify that when a GridSolv raises a critical fault on the fire safety system, GEMS locks the ESS unit(s) associated with that GridSolv.

3.3 Container HVAC Verification

A Wärtsilä engineer will verify HVAC status and commands are working properly.

4. BESS Plant Control and Performance Site Acceptance Test

This section describes the Site Acceptance Test (SAT) process for the Wärtsilä Battery Energy Storage System (BESS) power plant for the [Name] project.

It focuses on communication, control, performance and functional aspects of the plant.

For mechanical and electrical aspects, this section references equipment-specific checklists and test plans to be followed closely during commissioning.

The following tests should be executed before the BESS Plant Control and Performance SAT:

- Network Site Acceptance Test
- GridSolv Site Acceptance Test

All equipment installation checks must pass before any power up and control tests can be conducted.

4.1 PCS Installation Check

Wärtsilä or vendor engineer verifies all PCS units and transformers are installed according to design by following vendor provided PCS commissioning check list.

Verify the following:

- Ethernet cables are connected back to the managed switch in GridSolv 1.
- Device can be pinged from the controller in the GEMS Rack.
- Note: PCS Vendor technician will be on site for commissioning and startup processes. Support as needed once communication is established.
- Verify that all compartments are dry and free of dust and debris.
- Verify that all incoming terminations are torqued and marked

Work with PCS vendor engineers to verify that all PCS controller settings are correct. The settings include:

- PCS DC protection settings including over / under voltage protection settings and over current protection setting.
- PCS AC projection settings include over / under voltage protection settings, over / under frequency settings
- For grid-tied plant: PCS anti-islanding settings.
- For island plant: PCS frequency and voltage droop settings, and short circuit support configurations.
- PCS heartbeat timeout should be configured correctly according to GEMS requirement.

Note:

- *PCS control settings are different between grid-tied and islanding solutions.*
- *PCS control settings are different between PCS vendors.*
- *Please use the solution standard setting agreed with PCS vendor, customized for the project if needed, and documented before commissioning.*

4.2 Balance of Plant Installation Check

Wärtsilä engineer will make sure all Balance of Plant (BOP) equipment including switchgears and power meters are installed according to design by following vendor provided equipment commissioning check list.

(Section to be customized per project reflecting actual BOP equipment installed.)

4.3 GEMS PPC Site Communication Verification

4.3.1 Site VPN Remote Access

VPN connection should be established between Wärtsilä and the plant site.

Wärtsilä engineer verifies that they can access on-site GEMS controllers via SSH and HMI from Wärtsilä service center via VPN connection.

4.3.2 GEMS Fleet Director Verification

Via VPN connection, Wärtsilä engineer verifies that GEMS PPC can communicate with GEMS Fleet Director (FD) successfully.

4.4 Balance of Plant Verification

4.4.1 Meter Verification

Wärtsilä engineer will verify GEMS reports the correct voltage, amperage and frequency readings from the Site Meter and the Auxiliary Meter.

4.4.2 Switchgear Verification

Wärtsilä engineer will verify GEMS reports the correct status from all switchgears.

4.4.3 Other Devices

(Add other non-standard BOP devices here)

Wärtsilä engineer will verify GEMS records the correct status of all other project specific BOP devices not covered in our standard commissioning plan.

4.5 ESS Unit Verification

Wärtsilä engineer confirms the operation of all BESS Units by verifying each the battery bank and PCS.
The GEMS Rule Engine should be disabled, and the site should be in the manual control mode in order to allow the execution of the ESS Unit Verification tests.

4.5.1 GEMS PPC Battery Setting Verification

Wärtsilä engineer verifies the following GEMS battery operation settings with the battery vendor engineer and ensure that are configured correctly at GEMS controller:

- Maximum cell charge voltage limit of x.xx V
- Minimum cell discharge voltage limit of x.xx V
- Maximum battery operation SOC limit of xx.x%
- Minimum battery operation SOC limit of xx.x%
- Minimum battery string charge current limit of x.x Amp. This is the current limit below which operation should stop when charging battery to 100% SOC
- These values vary by supplier and model. Refer to vendor installation manual for the correct values.

4.5.2 Battery Status Reading Verification

Wärtsilä engineer verifies that GEMS PPC can establish communications with all battery BMS controllers.

Via GEMS PPC HMI, verify the following key battery readings from each battery rack:

- SOC
- SOH
- Maximum cell voltage
- Maximum cell voltage location
- Minimum cell voltage
- Minimum cell voltage location
- Maximum cell temperature
- Maximum cell temperature location
- Minimum cell temperature
- Minimum cell temperature location
- Battery string DC voltage
- Battery string DC current
- Maximum charge DC current
- Maximum discharge DC current

Each battery rack (string) DC voltage reading by GEMS should be compared with voltage reading by multi-meter between the positive and negative terminals of the battery rack to verify that they are consistent.

Wärtsilä engineer will make sure that the key measurements are uniform and consistent with battery bank readings.

4.5.3 Battery Control Verification

In this test, Wärtsilä engineer ensures that the DC bus manual disconnects for all battery banks are open. A high-precision multimeter is installed to measure DC bus voltage for the battery bank under test.

Test steps for each battery bank:

1. Verify that DC contactors for all battery strings are open and DC bus voltage reported by multimeter is zero.
2. Verify that all battery strings in the same battery bank has less than 3V in string voltage variation
3. Via GEMS PCS HMI, issue start battery bank command. Verify that all battery strings are connected to the DC bus without fault. Record the time between when the command is issued and when all battery string contactors are closed.
4. Compare the multimeter measured DC bus voltage against each battery string's BMS reported string voltage. Make sure that they are within 2% of each other.
5. Via GEMS HMI, stop battery bank. Verify that all battery strings are disconnected from the DC bus without fault, and that DC bus voltage reported by multimeter is zero.

4.5.4 PCS Communication, Control and Battery Charge/Discharge Test

For each PCS, conduct the following steps:

1. Confirm that the manual DC disconnect for the battery bank under test is closed.
2. Confirm that the manual DC disconnects for all other battery banks are open.
3. Confirm that all PCSs that are not under test are in the shutdown state.
4. Confirm that the circuit breaker of the feeder for the PCS under test is closed so that the PCS is connected to the grid.
5. Confirm that the GEMS controller can communicate with PCS.
6. Confirm that the PCS is at shutdown status and has no fault.
7. Via GEMS HMI, start battery bank.
8. Via GEMS HMI, start PCS. Verify that PCS starts successfully without fault.
9. Via GEMS HMI, command PCS at various real power levels from -x.x MW to x.x MW using x.x MW power step. Usually start with few KW (like 100/200 KW) steps. At each power level, verify the following:
    a. Reported DC current values of all battery strings. Verify that DC current values are uniform across battery strings, they are positive when charging and negative when discharging.
    b. Reported SOC of all battery strings. Verify that they are uniform across battery strings, they increase when charging and decrease when discharging.
    c. Reported maximum cell voltage and minimum cell voltage of all battery strings. Verify that they are uniform across battery strings and no significant differences between maximum cell voltage and minimum cell voltages at various power levels.
    d. Reported maximum battery cell temperature and minimum battery cell temperature across of battery strings. Verify that they are uniform across battery strings, no significant difference between maximum cell temperature and minimum cell temperature at various power levels.
    e. Verify that there are no alarms from either PCS or battery BMS during the test. Record any alarm if ever reported by BMS.
10. Via GEMS HMI, stop PCS. Verify that PCS stops successfully without fault.
11. Via GEMS HMI, stop battery bank. Verify that all battery strings disconnect from the DC bus successfully without fault.

4.5.5 PCS Power Control Precision and Response Time Verification

(PCS Power Control Precision and Response Time Verification is only applicable for projects with PCS in current-source (grid-tied) mode. Remove this section if PCS is in voltage-source (islanding) mode.)

PCS calibration is to ensure that PCS output power is as accurate as possible and is initiated at an acceptable response time. This calibration needs only be conducted at one PCS and the results used to configure all other PCS units.

Test steps:

1. Confirm that the DC Disconnect for the battery bank being tested is closed.
2. Confirm that all other DC Disconnects are open.
3. Confirm that all other PCSs are at shutdown state.
4. Confirm that the circuit breaker of the feeder for the PCS under test is closed so that the PCS is connected to the grid.
5. Verify with PCS engineer on-site that close-loop controls are turned on for both real and reactive power outputs on all PCS units.
6. Via GEMS PPC HMI, start ESS unit.
7. Via GEMS PPC HMI, execute PCS power precision test script using the PCS installed AC meter at AC terminal as reference, with power level from -x.xx KW to x.xx KW with x.x KW power step.
8. When test finished, provide power results that contains power command and power reading data to PCS vendor engineer on site to configure power control on all PCS units.
9. For each PCS, via GEMS PPC HMI, re-execute PCS power precision test script using the PCS installed AC meter at AC terminal as reference, with power level from -x.xx KW to x.xx KW with x.x KW power step. Verify that all PCS real power outputs reach within 97% of commanded power level and remain within 3% of error until next power command is sent out.
10. Adjust GEMS update interval on PCS installed AC meter at AC terminal to <= 100 ms.
11. Via GEMS PPC HMI, execute PCS power response time test operation using the PCS installed AC meter at AC terminal as reference, with power level from -x.xx KW to x.xx KW with x.x KW power step and 3% as allowed error margin.
12. Verify that all PCS real power outputs reach within 97% of commanded power level within 200ms and remain within 3% of error until next power command is sent out.
13. Document the test results at all power levels to spreadsheet. Notify project manager if the PCS power control fails to meet either accuracy or response time requirements at any power levels.

When the precision and response time of PCS has been verified and calibrations have been applied to all PCSs, the response time test should be repeated at for the site ESS to verify that the BESS output power at plant level at the Point of Interconnect (POI) with the grid also meets the response time requirements for the project.

Note

1. *This is **minimum** requirement based on our current PCS vendor selection and promise. We need to hold the equipment to meet the requirements even project-specific requirement is more relaxed.*

2. *For certain projects, the requirements can be much more stringent. Please replace with **smaller** numbers if project demands such.*
3. *For grid-tied projects requiring islanding functionality from the PCS, copy the PCS Voltage Source Mode tests from the IslandGrid+ SAT plan template.*

4.6 Plant Power Control Accuracy Verification

This test to ensure BESS output powers at plant level at the Point of Interconnect (POI) with the grid, normally at medium or high voltage, measured by the site meter, is as accurate as possible.

The GEMS Rule Engine should be disabled, and the site should be in the manual control mode in order to allow the execution of the Plant Power Control Accuracy Verification tests.

4.6.1 Plant Power Open Loop Calibration (if applicable)

When open loop control is used, power losses from PCS terminals to the site meter at the medium or high voltage point, mainly due to transformer losses, should be compensated by this calibration.

Calibration steps:

1. Confirm circuit breakers of the feeders for all the PCS units under test are closed.
2. Confirm DC bus manual disconnects for all battery banks under test are closed.
3. Via GEMS HMI, set site ESS to local mode.
4. Via GEMS HMI, attach all ESS units under test to site ESS.
5. Via GEMS HMI, execute site BESS power precision test script using power readings using the site meters as reference, with power level from site ESS's maximum charge power limit to maximum discharge power limit.
6. When test finished, use the result data that contains power commands and corresponding power readings to configure GEMS's Site ESS power control compensation.
7. After power control compensation adjustment is made, via GEMS HMI, re-execute site BESS power precision test operation using power readings using the site meters as reference, with power level from site ESS's maximum charge power limit to maximum discharge power limit. Verity that measured site power at each power level meets the precision requirement for the project.

(Note: if open loop control has trouble to meet precision requirement at all power levels, consider switch to close loop control.)

4.6.2 Plant Power Close Loop Adjustment

(This section is only applicable if close loop control is used for power plant power control using site meter as feedback.)

Adjustment steps:

1. Via GEMS HMI, execute site BESS power precision test script using power readings using the site meters as reference, with power level from site ESS's maximum charge power limit to maximum discharge power limit.
2. Based on test results, adjust close-loop control parameters, such as gain factor.

3. Repeat step 1 and 2 until measured site power at each power level meets both precision and response time requirement for the project

4.7 ESS Battery Capacity Test

The Wärtsilä engineer verifies the BESS battery capacity.

The ESS battery capacity test plan is described in the "ESS_Capacity_Test_Plan" section 5.

4.8 Site Operation Verification

(Test content should be developed for each project specific operation logic per functional specifications and site constraints. Below are some common on-grid operation test procedures.)

Each project-required operation should be activated manually and tested individually with GEMS Rule Engine disabled.
The test result of each operation should be documented into overall SAT report.

4.8.1 P/Q External Signal Handling Operation (if applicable)

Exercise Reactive Power control as follows:

1. Disable the Rule Engine in GEMS.
2. Set all ESS units as participating.
3. Start the External Power Signal Operation
   a. Power Signal Timeout = 300,000ms
   b. Power Signal Timeout Adjustment = 20,000ms
   c. Expired Signal Wait Time = 60,000ms

The system will operate according to the SCADA interface and follow real and reactive power commands.

4.8.2 Frequency-Watt Response Operation (if applicable)

Exercise the Frequency-Watt Operation as follows:

1. Disable the Rule Engine in GEMS.
2. Set all ESS units as participating.
3. Start the Frequency-Watt Operation with the following default parameters:
   a. Minimum Frequency Change (dF1) = -0.2Hz
   b. Minimum Deadband Frequency Change (dF2) = -0.05Hz
   c. Maximum Deadband Frequency Change (dF3) = 0.05Hz
   d. Maximum Frequency Change (dF4) = 0.02Hz
   e. Maximum Real Power (P1) = TBD kW
   f. Minimum Real Power (P4) = TBD kW
   g. Power Offset = TBD kW
4. Inject frequency reading to the Site Meter to test real power output at:
   a. Nominal frequency
   b. Frequency within deadband
   c. Over frequency

   d. Under frequency

4.8.3 Droop-Based Frequency Response Operation

Exercise the Frequency Operation as follows:

1. Disable the Rule Engine in GEMS.
2. Set all ESS units as participating.
3. Start the Frequency-Watt Operation with the following default parameters:
   a. Frequency Deviation (df1) = -0.5Hz
   b. Frequency Deviation (df2) = -0.02Hz
   c. Frequency Deviation (df3) = -0.01Hz
   d. Frequency Deviation (df4) = 0.01 Hz
   e. Frequency Deviation (df5) = 0.02 Hz
   f. Frequency Deviation (df6) = 0.5 Hz
   g. Real Power Factor (P1) = 100%
   h. Real Power Factor (P2) = 3%
   i. Real Power Factor (P5) = -3%
   j. Real Power Factor (P6) = 100%
4. Inject frequency reading to the Site Meter to test real power output at:
   a. Nominal frequency
   b. Frequency less than df1.
   c. Frequency in [df1, df2] band.
   d. Frequency in [df2, df3] band.
   e. Frequency in [df3, df4] band.
   f. Frequency in [df4, df5] band.
   g. Frequency in [df5, df6] band.
   h. Frequency more than df6.

4.8.4 Voltage-VAR Response Operation (if applicable)

Exercise the Voltage-VAR Operation as follows:

1. Disable the Rule Engine in GEMS.
2. Set all ESS units as participating.
3. Start the Voltage-VAR Operation with the following default parameters:
   a. Minimum Voltage Change (dv1) = -50 V
   b. Minimum Deadband Voltage Change (dv2) = -20 V
   c. Maximum Deadband Voltage Change (dv3) = 20 V
   d. Maximum Voltage Change (dv4) = 50 V
   e. Maximum Reactive Power (Q1) = TBD kVAr
   f. Minimum Reactive Power (Q4) = TBD kVAr
4. Inject voltage reading to the Site Meter to test reactive power output at:
   a. Nominal voltage
   b. Voltage within deadband
   c. Over voltage
   d. Under voltage

4.9 GEMS Rule Engine Verification

(Test content should be developed for each project specific operation logic per functional specifications and site constraints.)

GEMS Rule Engine configurations for the project should be verified. GEMS Rule Engine should then be enabled. Wärtsilä engineer should manually create various conditions to ensure that all rules can be triggered correctly.

4.10 SCADA Verification

(Test content should be developed for each project specific operation logic per functional specifications and site constraints.)

4.11 GEMS PPC High-Availability Failover Verification

Test steps:

1. Power down or disconnect the primary GEMS PPC controller
2. Verify that the secondary GEMS PPC controller successfully takes over the power plant control without interruption in terms of: data monitoring, HMI, SCADA service, manual control and operation automation.
3. Verify that fail-over alarm is raised and visible at HMI
4. Power up or reconnect the primary GEM PPC controller and execute the recovery procedure.
5. Verify that the primary GEMS PPC controller successfully takes over the power plant control without interruption in terms of: data monitoring, HMI, SCADA service, manual control and operation automation.

4.12 Documentation

After all required testing and verification has been completed, the Wärtsilä engineer documents additional information, including:

- Take pictures of the installation during and after commissioning
- Record Serial numbers for all major components
  - Rack Switchgears (use QR code scanner)
  - Battery modules (use QR code scanner)
  - PCS units
  - HVAC units
  - FACP & VESDA panels
  - Suppression agent tank
  - All Spare Parts
- Upload the data into SQAD forms (in pdf format if possible).

5. ESS Capacity Site Acceptance Test

This section describes the ESS Capacity Site Acceptance Test for the [Name] project.

Select either Site ESS or ESS Unit Capacity Test

5.1 Site ESS Battery Capacity Test

Test steps:

1. Confirm that DC bus manual disconnects for all battery banks are closed.
2. Confirm that circuit breakers for the feeders for all the PCS units are closed.
3. Put the Site ESS in Local Mode.
4. Make sure that all ESS units under test are attached to site ESS.
5. Start the Site ESS
6. Execute Target SOC operation at Site ESS at maximum allowed discharge power to discharge all battery banks involved to 0% SOC (this number can be modified based on project requirement). A battery bank will stop discharge when its battery reaches the SOC target or when any cell voltage reaches minimum cell voltage protection limit configured at GEMS PPC.
7. During the discharging process, verify that total battery bank discharge power limit does not drop below x.x MW during the entire test.
8. When discharge finishes at any ESS unit, record the following:
   a. Minimum cell voltage and maximum cell voltage of the battery bank.
   b. Minimum cell voltage and maximum cell voltage of each battery string in the battery bank
   c. SOC for the battery bank
   d. SOC for each battery string in the battery bank
9. When discharge finishes at any ESS unit, record the following:
   a. AC charged energy for each ESS unit.
   b. DC charged energy for each battery bank
   c. DC charged energy for each battery string.
10. Discuss test results with battery engineer to verify everything is normal and expected.
11. Rest battery for 20 minutes.
12. Start the Site ESS.
13. Execute the Target SOC operation at Site ESS at the maximum allowed charge power to charge all battery banks to 100% SOC (this number can be modified based on project requirement).
14. During the charging process, GEMS will reduce charging power for a unit when any battery cell voltage reaches maximum cell voltage limit configured at GEMS PPC. A battery bank will stop charging when either the target SOC is reached or when battery string's current drop below minimum battery string charge current limit.
15. When the charge finishes at any ESS unit, record the following:
    a. Minimum cell voltage and maximum cell voltage of the battery bank.
    b. Minimum cell voltage and maximum cell voltage of each battery string in the battery bank
    c. SOC for the battery bank
    d. SOC for each battery string in the battery bank
16. When the charge finishes at any ESS unit, Record the following:
    a. DC discharged energy for each battery bank.

b. DC discharged energy for each battery string in the bank.
c. AC discharged energy for each ESS unit.
d. DC charged energy for each battery bank. Compare DC charged energy counter recorded in last full discharge step to calculate chargeable energy capacity for the battery bank.
e. DC charged energy for each battery string. Compare DC charged energy counter for the same string recorded in last full discharge step to calculate chargeable energy capacity for the battery string.
f. AC charged energy for ESS unit. Compare AC charged energy counter for the same ESS unit in the last full discharge stop to calculate chargeable AC energy capacity for the ESS unit.

17. Discuss test results with battery engineer to verify everything is normal and expected.
18. Rest battery for 20 minutes.
19. Execute Target SOC operation on the Site ESS at the maximum allowed discharge power to discharge all battery banks to 0% SOC.
20. During the discharging process, verify that total battery bank discharge power limit does not drop below xx.xx s MW during the entire test.
21. When the discharge finishes at any ESS unit, record the following:
    a. Minimum cell voltage and maximum cell voltage of the battery bank.
    b. Minimum cell voltage and maximum cell voltage of each battery string in the battery bank
    c. SOC for the battery bank
    d. SOC for each battery string in the battery bank
22. When the discharge finishes at any ESS unit, stop the ESS unit when the discharge is finished to prevent further power exchange between battery and PCS.
23. Record the following:
    a. DC discharged energy for each battery bank. Compare discharged energy counter recorded in last full charge step to calculate DC dischargeable energy capacity for the battery bank.
    b. DC discharged energy for each battery string. Compare discharged energy counter for the same string recorded in last full charge step to calculate DC dischargeable energy capacity for the battery string.
    c. AC discharged energy for each ESS unit. Compare AC discharged energy counter for the same ESS unit recorded in the last full charge step to calculate AC dischargeable energy capacity for the ESS unit
24. Verify the battery bank dischargeable energy capacities against the contracted numbers.
25. Calculate the following:
    a. Battery efficiency for each battery bank by comparing DC dischargeable energy capacity and DC chargeable energy capacity.
    b. Round-trip efficiency for each ESS unit by comparing AC dischargeable energy capacity and AC chargeable energy capacity.
    c. Charge AC-DC efficiency for each PCS by comparing AC chargeable energy capacity of the ESS unit and DC chargeable energy capacity of the battery bank.

d. Discharge DC-AC efficiency for each PCS by comparing AC dischargeable energy capacity of ESS unit and DC dischargeable energy capacity of the battery bank.

Use Battery Capacity Test Result spreadsheet to record all data points and calculations of battery capacity test. Use the report to verify the following:

- All battery module temperatures stayed within battery vendor defined range during the test.
- All battery container environmental temperatures stay within vendor specified range during test.
- Temperature deviations across battery racks in any container stayed within range during test.
- Temperature deviations cross modules in any rack stayed within range.
- At the end of full discharge, the minimum cell voltages of all racks within the same bank are close to each other. The difference between maximum and minimum cell voltage in any rack are within range.
- At the end of full charge, the maximum cell voltage of all racks within the same bank are close to each other. The difference between maximum and minimum cell voltage in any rack are within range.
- The Site ESS SOC at the end of full discharge meets expectation.
- The Site ESS SOC at the end of full charge meets expectation.
- Battery DC discharge capacity meet agreement by battery vendor to Wärtsilä.
- Site ESS AC discharge capacity meet agreement by Wärtsilä to customer.
- Battery DC-DC efficiency meet agreement by battery vendor to Wärtsilä.
- Battery AC-AC efficiency meet agreement by battery Wärtsilä to customer.
- PCS charge and discharge efficiency meet agreement by PCS vendor to Wärtsilä.

5.2 ESS Unit Battery Capacity Test

(Option 1: Use when it is possible to connect the BPP to the grid formed by other generation assets with load, and conduct capacity test of all ESS units together. Use Site ESS Capacity Worksheet.)

1. Form the grid by xx generation asset with load that can handle battery charge and discharge powers at xx MW level.
2. Set the PCSs of all PCS units to current source mode. *(May be necessary to divide the test into separate PCS groups to minimize impact on the grid, depending on BPP sizing)*
3. Connect all PCSs to the grid and start each unit.
4. Follow the procedure described in the ESS Capacity and Efficiency SAT document.

(Option 2: Use when it is applicable when it is not possible to connect the BPP to the grid formed by other generation assets with load. It is possible to test multiple ESS Units at once given enough voltage source ESS Units are available. Use Unit ESS Capacity Worksheet)

1. Disconnect the BPP from the grid.
2. Choose one third of ESS units (Target Units) to run at current source (CS) mode; two thirds of ESS units to run in voltage source mode to provide energy to Target Units during charge phase and absorb energy from Target Units during discharge phase.
3. Follow the procedure described in the ESS Capacity and Efficiency SAT document to verify the energy capacity and power efficiency of the Target Units.

Choose different Target Units until all ESS units installed for this project is tested.

(Option 3: Use when it is possible to connect the BPP to a large grid capable of absorbing large changes in load. Use ESS Unit Capacity Worksheet and remove steps using other units in voltage source.)

1. Set the PCSs of all PCS units to current source mode.
2. Connect all PCSs to the grid and start each unit.
3. Follow the procedure described in the ESS Capacity and Efficiency SAT document.

Test steps:

1. Confirm that DC bus manual disconnects for all battery banks are closed.
2. Confirm that circuit breakers for the feeders for all the PCS units are closed.
3. Put the Site ESS in Local Mode.
4. Make sure that all ESS units under test are attached to site ESS.
5. Start the Site ESS
6. Put each ESS Unit in Voltage Source Mode
7. Set testing ESS Unit in Current Source Mode
8. Execute Target SOC operation at Testing ESS Unit at maximum allowed discharge power to discharge unit to 0% SOC (this number can be modified based on project requirement). The Unit will stop discharge when its battery reaches the SOC target or when any cell voltage reaches minimum cell voltage protection limit configured at GEMS PPC.
9. During the discharging process, verify that total battery unit discharge power limit does not drop below x.x MW during the entire test.
10. When discharge finishes at the unit, record the following:
    a. Minimum cell voltage and maximum cell voltage of the battery unit.
    b. Minimum cell voltage and maximum cell voltage of each battery string in the battery unit
    c. SOC for the battery unit
    d. SOC for each battery string in the battery unit
    e. AC charged energy for the ESS unit.
    f. DC charged energy for the battery unit
    g. DC charged energy for each battery string.
11. Discuss test results with battery engineer to verify everything is normal and expected.
12. Rest battery for 20 minutes.
13. Execute the Target SOC operation at ESS Unit at the maximum allowed charge power to charge the battery unit to 100% SOC (this number can be modified based on project requirement).
14. During the charging process, GEMS will reduce charging power for a unit when any battery cell voltage reaches maximum cell voltage limit configured at GEMS PPC. The battery bank will stop charging when either the target SOC is reached or when battery string’s current drop below minimum battery string charge current limit.
15. When the charge finishes at the ESS unit, record the following:
    a. Minimum cell voltage and maximum cell voltage of the battery unit.
    b. Minimum cell voltage and maximum cell voltage of each battery string in the battery bank
    c. SOC for the battery bank

   d. SOC for each battery string in the battery bank
   e. DC discharged energy for the battery bank.
   f. DC discharged energy for each battery string in the bank.
   g. AC discharged energy for the ESS unit.
   h. DC charged energy for the battery bank. Compare DC charged energy counter recorded in last full discharge step to calculate chargeable energy capacity for the battery bank.
   i. DC charged energy for each battery string. Compare DC charged energy counter for the same string recorded in last full discharge step to calculate chargeable energy capacity for the battery string.
   j. AC charged energy for ESS unit. Compare AC charged energy counter for the same ESS unit in the last full discharge stop to calculate chargeable AC energy capacity for the ESS unit.

16. Discuss test results with battery engineer to verify everything is normal and expected.
17. Rest battery for 20 minutes.
18. Execute Target SOC operation on the ESS Unit at the maximum allowed discharge power to discharge all battery banks to 0% SOC.
19. During the discharging process, verify that total battery bank discharge power limit does not drop below xx.xx s MW during the entire test.
20. When the discharge finishes at the ESS unit, record the following:
    a. Minimum cell voltage and maximum cell voltage of the battery bank.
    b. Minimum cell voltage and maximum cell voltage of the battery string in the battery bank
    c. SOC for the battery bank
    d. SOC for each battery string in the battery bank
21. When the discharge finishes at the ESS unit, stop the ESS unit when the discharge is finished to prevent further power exchange between battery and PCS.
22. Record the following:
    a. DC discharged energy for the battery bank. Compare discharged energy counter recorded in last full charge step to calculate DC dischargeable energy capacity for the battery bank.
    b. DC discharged energy for each battery string. Compare discharged energy counter for the same string recorded in last full charge step to calculate DC dischargeable energy capacity for the battery string.
    c. AC discharged energy for the ESS unit. Compare AC discharged energy counter for the the ESS unit recorded in the last full charge step to calculate AC dischargeable energy capacity for the ESS unit
23. Verify the battery bank dischargeable energy capacities against the contracted numbers.
24. Calculate the following:
    a. Battery efficiency for each battery bank by comparing DC dischargeable energy capacity and DC chargeable energy capacity.
    b. Round-trip efficiency for the ESS unit by comparing AC dischargeable energy capacity and AC chargeable energy capacity.

c. Charge AC-DC efficiency for each PCS by comparing AC chargeable energy capacity of the ESS unit and DC chargeable energy capacity of the battery bank.
d. Discharge DC-AC efficiency for each PCS by comparing AC dischargeable energy capacity of ESS unit and DC dischargeable energy capacity of the battery bank.

Use Battery Capacity Test Result spreadsheet to record all data points and calculations of battery capacity test. Use the report to verify the following:

- All battery module temperatures stayed within battery vendor defined range during the test.
- All battery container environmental temperatures stay within vendor specified range during test.
- Temperature deviations across battery racks in any container stayed within range during test.
- Temperature deviations cross modules in any rack stayed within range.
- At the end of full discharge, the minimum cell voltages of all racks within the same bank are close to each other. The difference between maximum and minimum cell voltage in any rack are within range.
- At the end of full charge, the maximum cell voltage of all racks within the same bank are close to each other. The difference between maximum and minimum cell voltage in any rack are within range.
- ESS Unit SOC at the end of full discharge meets expectation.
- ESS Unit SOC at the end of full charge meets expectation.
- Battery DC discharge capacity meet agreement by battery vendor to Wärtsilä.
- ESS Unit AC discharge capacity meet agreement by Wärtsilä to customer.
- Battery DC-DC efficiency meet agreement by battery vendor to Wärtsilä.
- Battery AC-AC efficiency meet agreement by battery Wärtsilä to customer.
- PCS charge and discharge efficiency meet agreement by PCS vendor to Wärtsilä.