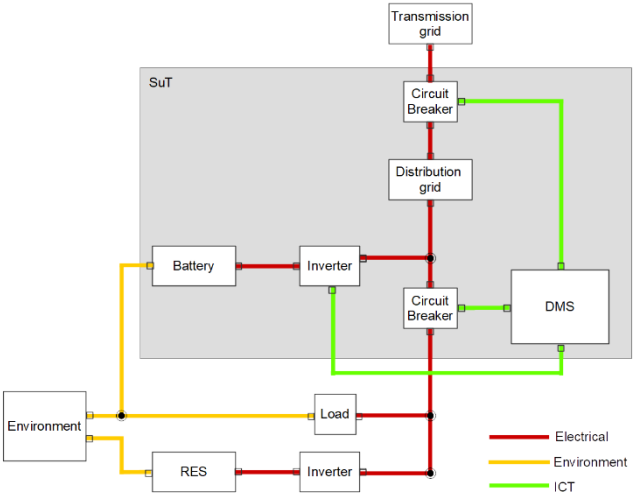# Test Case 16

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Name of the Test Case	Testing Black-Start capability using distributed converted interfaced resources
Narrative Incl. use case and test objectives.	The focus of this TC is on MV distribution grid where one central controller can perform the following actions: isolate/disconnect/ reconnect lines and/or resources and initiate grid-forming DGs. The DGs that provide the BS service should have resilience in significant frequency/voltage variations to cope with large imbalances during re-energization and for a typical duration of at least 1 hour. The scope of the TC is to verify the system's ability to achieve a smooth re-energization within the prescribed duration.
Function(s) under Investigation (*FuI*) "the referenced specification of a function realized (operationalized) by the object under investigation"	• Black-start control • Primary voltage control • Primary frequency control • Secondary frequency control • Secondary voltage control
Object under Investigation (*OuI*) "the component(s) (1..n) that are to be qualified by the test"	• Distribution Management System (as the provider of the BS and secondary control functionalities) • Inverter-based DGs (as providers of the power/energy needed for system re-energization and as primary control resources)
Domain under Investigation (*DuI*): "the relevant domains or sub-domains of test parameters and connectivity."	• Electrical Power • ICT (time-delays) • Electrochemical • Environmental
Purpose of Investigation *(PoI)* The test purpose in terms of Characterization, Verification, or Validation	• Validation of Black-Start capability

System under Test (*SuT*): Systems, subsystems, components included in the test case or test setup.	 The main components and subsystems that are of interest for this TC are depicted in the above diagram and summarized below: • Distribution Management System (DMS) • Circuit breakers • Battery energy storage system (BESS) • Distribution Grid
Functions under Test (*FuT*) Functions relevant to the operation of the system under test, including FuI and relevant interactions btw. OuI and SuT.	• Battery Management System • MPPT • Load control • SCADA • Energy Management System
Test criteria *(TCR)* Formulation of criteria for each PoI based on properties of SuT; encompasses properties of test signals and output measures.	• Frequency response • Voltage response • Battery capacity
Target Metrics *(TM)* Measures required to quantify each identified test criteria	• Maximum Voltage deviations (±5%) • Maximum frequency deviations (47.5 Hz–52 Hz) • Maximum ROCOF • Response/stabilization time • Maximum Energy Availability • Number of sequential start-ups (at least three)
Variability Attributes *(VA)* controllable or uncontrollable factors and the required variability; ref. to PoI.	Fully Controllable attributes: • Circuit breakers' state • Primary and secondary control parameters • Inverter control functionalities Partly Controllable attributes: • Loads' active/reactive power

	• Generators' active/reactive power Uncontrollable attributes: • Solar irradiation • Wind speed • Ambient temperature • ICT and control delays

Quality Attributes *(QA)*
threshold levels for test result quality as well as pass/fail criteria.
	• Sampling time of signals (frequency, voltages, Power/energy flows): <1sec
	• Resolution:
	   ○ frequency 0.05 Hz,
	   ○ voltage 0.005 pu
	   ○ Power 0.01pu
	• Points of measurement:
	   ○ Frequency: at least 1
	   ○ Voltage: 1 point for each resource connected at their electrical output
	   ○ Battery power/energy flow: 1 point at the output of the BESS

Qualification Strategy

In order to meet the specific PoI, which is the evaluation of the distribution system's Black Start capability, three separate test specifications are required:
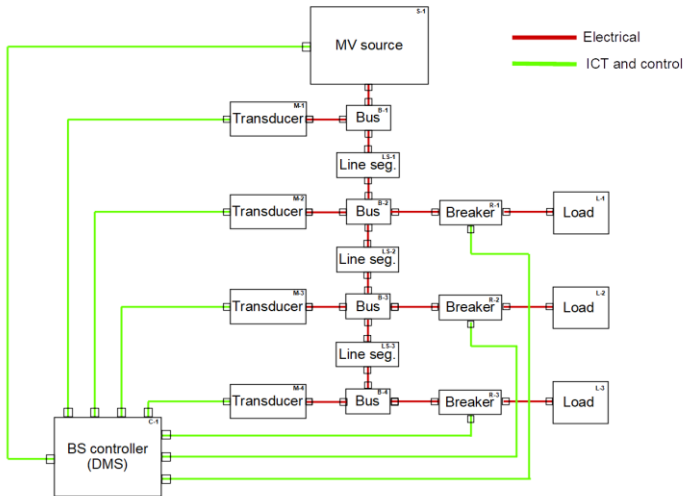
-One test is related to the partitioning of the system. That is how the centralized BS controller manages to disconnect and reconnect components of the grid, either resources (loads, generators) or lines. The test validates the correctness of the disconnection order of components, as well as the ability of the controller to reconnect them at times when voltage and frequency are well within specific boundaries and more or less stable.

-The second test verifies the ability of the system to maintain voltage and frequency within specific boundaries after the BS generator is started up by the BS central controller. The specific operating limits for this test are more relaxed as opposed to the ones that apply in normal operation.

-The third test is a sort of endurance test which validates the BS generator's ability to provide the service for a minimum time duration (e.g., 1 hour). In other words, this test comes down to verifying the energy reserve of the BS generator.

Test Specification 16.01

Reference to Test Case	TC16
Title of Test	Black Start algorithm verification
Test Rationale	This test verifies the ability of the centralized BS controller to disconnect/reconnect parts of the grid and resources in the right order and at the right timing. The order of actions is fixed and predefined through the programming parameters of the control system, whereas the reconnection timing should happen automatically at times when voltage and frequency are within specific boundaries.

Specific Test System (graphical)	
	  The test setup depicted above comprises one BS controller (as part of the DMS), three loads with controllable switches, three transducers for the voltage measurement at each load (on the breaker's side), one transducer for the measurement of frequency and one controllable source which provides the voltage/frequency controllability required for validating the controller behavior.
Target measures	• Power outage time • Reconnection times • Voltage/frequency values
Input and output parameters	Input parameters • Frequency • Voltage Output parameters • Breaker state • Load voltage • Controllable source activation
Test Design	The specific test makes use of the controllable MV source to emulate the blackout condition as well as the BS generation provider. Therefore, the source's output can be deactivated manually and reactivated through a communication signal from the BS controller. In the real system, the specific signal is the start-up command from the BS controller to the BS generator. The voltages at each load should be monitored on either end of the breaker in order to verify: • Disconnection/reconnection time • If the voltage conditions for reconnection are suitable Moreover, by monitoring the frequency at the source's output it is possible to: • Verify that the controller reconnects the loads within the proper frequency conditions and in the right order • Verify that the start-up command to the BS generator is communicated correctly and in the right order Even though some voltage/frequency stability is presumed for the test, the limits for these values, especially frequency should be not considered as tight as in normal operation. Therefore, the frequency limits for this test are considered from 47.5 to 52 Hz with a

	ROCOF <2 Hz/s. The corresponding voltage limits are considered as +5% and -5% of the nominal voltage.
Initial system state	• The controllable source supplies the system with constant voltage at frequency at nominal values (f_{source}=50 Hz, V_{source}=1 p.u.) • The three breakers are closed, and the loads are supplied • The BS controller is reset to its initial state (normal operation) • The BS controller continuously monitors frequency and voltages in order to detect a possible blackout
Evolution of system state and test signals	• At a predetermined moment, the source's output is deactivated and the voltage and frequency become zero emulating the blackout conditions • This time is recorded as reference for calculating the response times of the various components • The BS controller detects the loss of voltage and initiates the BS procedure • Initially, the BS controller disconnects all three loads from the grid • After a specific interval (<1 min), the BS controller dispatches the start-up signal to the controllable source • The output of the source is monitored in order to calculate the time required for this step until re-energization is restored • The BS controller continuously monitors the voltages and frequency in order to detect when the conditions are proper for reconnecting the loads • The load voltages are recorded to measure the reconnection order as well as the proper voltage/frequency conditions during reconnection
Other parameters	N/A
Temporal resolution	A sampling time of <1 s is enough for this test to provide the necessary information since the responses of the controller signals range in the order of several seconds to minutes.
Source of uncertainty	Uncertainties that may appear in this test are due to the precision of the various instruments used to measure the voltage/frequency responses. Additional uncertainties may be introduced by the communication channel delays between the BS controller and the various controllable components.
Suspension criteria / Stopping criteria	The test should be suspended and restarted if one of the quality attributes described in the TC is not met or if the algorithmic procedure of the BS controller does not perform as should be expected.

Test Specification 16.02

Reference to Test Case	TC16
Title of Test	Frequency and Voltage stability response during BS
Test Rationale	Once the BS generator is started by the BS controller to reenergize the grid, an interval follows within which several resources are reconnected. The main challenge that the BS generator and the system itself faces is the stability of frequency and voltage. Due to its nature, the requirements for this operating state should not be very strict. Nevertheless, rudimentary stability should always be maintained in order to avoid a new blackout. This test aims at evaluating the system's capability to cope with the imbalances and maintain frequency as well as voltage stability within the required limits.

Specific Test System (graphical)	The above test system is based on the MV distribution network benchmark application example by CIGRE[1]
Target measures	• ΔV_{max}=+5% to -5% of nominal voltage • Δf_{max}= from 47.5 to 52 Hz with a ROCOF <2 Hz/s.
Input and output parameters	Input parameters • Solar irradiance • Wind speed • Ambient temperature • Load consumption • Breaker state Output parameters • Frequency • Voltages
Test Design	The test is carried out in a way that emulates the system behaviour after a black out. This implies the initial disconnection of lines and loads through the controllable circuit breakers and the start-up of the BS generator (BESS on Bus B-5). In this way, the system is sectionalized to its minimal connectivity state.
Initial system state	• All circuit breakers are open • The BS generator is not running
Evolution of system state and test signals	• At a specific time within 1 min from the beginning of the test, the BS generator is started up • Frequency and voltages at various points of the grid are continuously monitored • After another time interval (e.g., 2-5 minutes) the first set of circuit breakers is reclosed to add the extra generation/load to the system. The time interval allowed for reconnection should be enough for quasi-stabilization of the system. • The previous step is repeated as many times as the number of circuit breaker groups are reclosed
Other parameters	N/A
Temporal resolution	A sampling time of <100 ms is required for the accurate measurement of frequency and voltage variations.
Source of uncertainty	Apart from the measurement uncertainties due to the instruments' accuracy, additional uncertainties may be introduced by the com-

	munication channel delays between the controller and the DER units. In addition to that, the system operation is subject to uncertainties due to: • Environmental conditions • Consumers' demand • Grid parameters variability, i.e., resistance and inductance
Suspension criteria / Stopping criteria	The test should be suspended and restarted if one of the quality attributes described in the TC is not met. If stability is not ensured during the various reconnection actions, the control parameters should be readjusted and the test repeated.

[1]CIGRE. Benchmark Systems for Network Integration of Renewable and Distributed Energy Resources; CIGRE Task Force C6.04.02; CIGRE: Paris, France, 2009

Test Specification 16.03

Reference to Test Case	TC16
Title of Test	BS generator energy availability test
Test Rationale	The BS generator must provide a sufficient amount of energy for at least 1 hour, in order for the system to cope with any uncertainties during the process. Such uncertainties may include failures in starting up other generators or instability problems. Also, uncertainties caused State of Health (SOH), ambient temperature, etc. may result in a deviation of the actual available energy of the BESS from its nominal value. The specific test addresses the ability of the BS generator to provide energy supply for at least 1 hour of continuous operation after the BS.
Specific Test System (graphical)	 The test system consists of a controllable and bidirectional MV source, one BESS comprising battery, inverter and BMS and one controller which can control the BESS's active and reactive power injection.
Target measures	• Battery SOC>10% • Operation time >1 h
Input and output parameters	Input parameters • Ambient temperature • Active and reactive power setpoints Output parameters • Active and Reactive Power • Active and Reactive Energy • SOC

Test Design	The test can consider various profiles for the setpoints of P and Q depending on the specifications and needs from each BS system. However, as the worst-case scenario, the maximum P should continuously be drawn from the BESS in order to examine the minimum time duration of the generator's availability.
Initial system state	- The battery is charged at a SOC>50% assuming that the system may participate in other services as well - The MV source is up and running at nominal voltage - The Inverter is connected to the MV source
Evolution of system state and test signals	- The PQ controller changes the setpoint for the active power to its maximum value. - The power flow is recorded at the bus together with the time that the flow of energy starts - In parallel, the SOC and battery voltage are monitored through the BMS - The discharging of the BESS continues until either 1-hour elapses or the SoC drops below 10%
Other parameters	N/A
Temporal resolution	A sampling time of 1 s is sufficient for monitoring the required quantities
Source of uncertainty	Sources of uncertainty for this experiment may be the SoH of the battery, the ambient temperature as well as the accuracy with which the BMS calculates the SOC. In addition, accuracies of measurement equipment may apply.
Suspension criteria / Stopping criteria	The test should be suspended if no maximum power absorption is obtained from the BESS. Also, if for some reason the BMS overrides the external control in order to prioritize other functions (e.g., recharge of the battery).