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Transition to Future Power Systems

Analysis of the applicability of the IEEE 2030.8 standard for testing a microgrid control system

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SUMMARY

To coordinate the operation of the different generating units, storage systems and loads belonging to a microgrid, typically a Microgrid Control System (MGCS) is needed. This MGCS defines the set points to be delivered to the controllable devices to guarantee the appropriate operation of the microgrid both from the technical and the economic perspectives. The MGCS must be able to operate the microgrid in islanded mode, grid-connected, and withstand the transitions between the two operating modes.

Recently two international standards have been approved dealing with microgrid controllers, “IEEE 2030.7-2017 – IEEE Standard for the Specification of Microgrid Controller” and “IEEE 2030.8-2018 - IEEE Standard for the Testing of Microgrid Controllers”. These standards provide guidelines to characterize and validate the operation of the controller functionalities to ensure reliable operation of the microgrid in the Point of Interconnection (PoI) between the microgrid and the main grid. The present work focuses on analysing the applicability of IEEE 2030.8-2018 to the MGCS at TECNALIA’s Smart Grid Technologies Laboratory (SGTL) located in Derio, Spain. These tests cover the specifications of IEEE 2030.8-2018 including the Dispatch Functions (both in grid-

connected and islanded operating modes) and the Transition Function (from grid-connected to islanded modes and the other way around).

The work has been done in the framework of the European ERIGrid project whose main objective is the development of an integrated research infrastructure at a pan-European level by involving Europe's top institutions to develop common testing methods, concepts and procedures. The definition of the tests has been done according to the Holistic Test Description (HTD) methodology developed in the project.

KEYWORDS

Microgrid, Testing Methodology, Microgrid Control System, Holistic Test Description

1. INTRODUCTION

A microgrid is a group of interconnected generating units, storage systems and loads that may operate both in islanded mode and grid-connected mode [1]. Microgrids are used for applications requiring high level of security in the electricity supply, for remote sites with weak grid connections, and for installations where the energy is managed more efficiently locally. Current trends indicate that the market share of microgrids will increase in the coming years with thousands of microgrid facilities installed and with an expectation of more than 25 GW of capacity installed worldwide [2].

A key aspect of guarantying the proper operation of a microgrid is its control system. Different control levels can be identified including primary, secondary and tertiary controls. Primary controllers of generators are in charge of ensuring the system's stability and real time sharing of load, secondary control is responsible for managing the system frequency and adapting the power set points after primary control operation, and the tertiary control plans with a longer time horizon the operation of the elements in the microgrid [3], [4]. The main objectives of the control system vary from ensuring a stable and secure operation to its optimization from an economical point of view depending on its operation mode (grid-connected or islanded).

There are several standards addressing the microgrid concept such as IEC TS 62898-1 for the planning and specification of microgrids [5], IEC TS 62898-3-1, defining microgrid protection requirements [6] and IEEE P1547 specifying microgrid connection requirements with distribution utilities [7] among others. Recently two new standards have been released: IEEE 2030.7 related to microgrid control system specification [8] and IEEE 2030.8 for the testing of microgrid controllers [9]. The aim of these standards is to help the deployment of microgrids by facilitating the development of interoperable solutions.

This paper describes a practical implementation of IEEE 2030.8 into a laboratory microgrid making use of the HTD methodology [10] developed in the ERIGrid project [11] to identify potential improvements for the standard and for the MCGS.

The paper is divided into five main sections: A brief description of the HTD methodology, a description of the laboratory microgrid set-up were tests were conducted, the definition of the tests following the guidelines of IEEE 2030.8, a summary of test results and potential improvements and finally the description of the main conclusions and future work.

2. OVERVIEW OF THE APPLIED VALIDATION METHODOLOGY

The goal of the HTD methodology developed within ERIGrid is to serve as a tool to guide researchers and engineers in the definition of complex tests by providing a sequential approach to the testing process. This tool is based on a set of templates and an associated graphical notation. The HTD allows to clarify the objectives, setups and essential parameters of the tests and to help in the mapping of the experiments to a certain laboratory.

The holistic test case serves as the basic pillar of the ERIGrid methodology utilizing a generic system configuration (GSC) under certain conceived use cases and one or more test objectives in order to determine and refine the test criteria. Main definitions to understand the use of the HTD in the implementation of the IEEE 2030.8 Test Cases (TC) for validating the behaviour of the MGCS under different conditions are summarized in *Table 1*. From an initial TC, different Test Specifications (TS) are derived to define the tests itself (but independent on the research infrastructure/laboratory). The mapping of the TS to a certain laboratory defines the Experiment Specifications (ES). Further information about the methodology can be found in [10].

Table 1: HTD concepts and definitions [10]

HTD term	Definition
System under Test (SuT)	A specific system configuration that includes all relevant properties, interactions and behaviours that are required for evaluating an Object under Investigation (OuI) as specified by the test criteria.
Object under Investigation (OuI)	The component(s) that are to be characterized or validated.
Domain under Investigation (DuI)	Identifies the relevant domains or sub-domains of test parameters and connectivity.
Function(s) under Test (FuT)	The functions relevant to the operation of the system under test, as referenced by the use cases.
Purpose of investigation (PoI)	A formulation of the relevant interpretations of the test purpose (in terms of characterization, verification or validation)

3. CHARACTERIZATION OF THE TEST SET-UP

The SuT used for the tests includes two power converters acting as generating units together with different resistive and inductive loads. These generating units and loads are electrically connected to a common busbar that at the same time is connected through a line impedance to the main switch. This switch is the one used for islanding and connecting the microgrid to the main grid and incorporates a synchro-check relay providing a safe grid connection capability. In addition to the mentioned elements, a grid simulator has been used in some tests, replacing the real grid connection in order to test disturbed conditions. *Figure 1* and *Table 2* show a graphical representation and the main characteristics of the SuT in the SGTL microgrid.

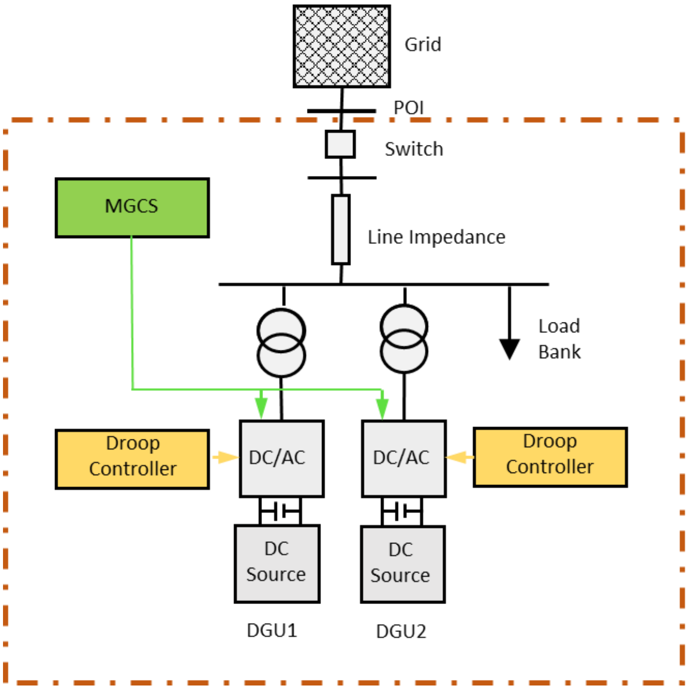

Figure 1: Microgrid Test set-up (SuT)

From the control system point of view, two control levels can be differentiated: 1) real-time low-level control implemented at each inverter control board and 2) high level control system for coordinating the different components of the microgrid). In Figure 1 they are named as Droop Controllers and MGCS and represent the primary and secondary controls respectively. When operating in grid-connected mode the operator can define a certain power schedule (import and export) at the PoI. When operating in islanded mode the operator settles a reference frequency to be maintained in the microgrid [12].

The droops of each inverter are implemented at a Digital Signal Processor (DSP)-based control board. In addition to this, the inverters contain an output L-C-L filter to smooth the switching harmonics and allow the connection with the grid. The converters can be programmed as grid-forming (voltage sources), or as grid-following (current sources).

Table 2: Main characteristics of the devices in the microgrid

Device	No	Description	Characteristics
DC/AC power converter	2	In house developed power converter using SEMIKRON IGBT modules	400 V AC (3Ph+N)50 kW
Avtron Millenium Load bank	1	Resistive load bank	400 V AC (3Ph) 150 kW (steps: 5,10,10,25,50,50)
Avtron K595 Load bank	1	Resistive load bank	400 V AC (3Ph) 37.5 kW (steps: 1.39, 2.78, 5.56, 11.11, 16.67)
Avtron K596 Load bank	2	Inductive load bank	400 V AC (3Ph) 36 kVAr (steps: 0.375, 0.75, 1.25, 2.5, 5, 10, 15)
REGATRON TC.ACS.50.528.4WR.S.LC	1	Programmable Bidirectional Regenerative AC Power Source	Output port: 0 – 400 VAC (3Ph), 0-1000 Hz ,0-72A, 0-50 kVA

The high-level control system is implemented as a multi-agent system which operates the microgrid following a market approach. On one hand, device level agents are software components linked to the physical devices of the microgrid and providing both technical and economic information to the microgrid level agents. The device level agents communicate with the different physical devices in the laboratory through Modbus-based communication protocol implemented through both Ethernet and serial communication networks. On the other hand, the microgrid level agents are in charge of monitoring the whole microgrid performance and use the information from device level agents to calculate and deliver appropriate set points.

4. DEFINITION OF TEST CASES

The main functions of a MGCS as defined in IEEE 2030.7 are the Dispatch Function and the Transition Function, each one associated to a reference TC: (i) TC1 for testing the Dispatch Function and (ii) TC2 for testing the Transition Function. The Dispatch Function (FuT in TC1) is the one dispatching the different controllable generating units and loads in the microgrid in order to fulfil a certain operating objective and must be tested in both grid-connected and islanded modes. In TC1 the PoI is the validation of the MGCS operation to maintain the power export and import as determined by the operator when the microgrid is connected to the main grid. In a similar way, when the microgrid is operating in islanded mode the PoI is the validation of the MGCS for maintaining the frequency to the nominal value (50 Hz). The TS for the testing of the Dispatch Function consider the power exchange with the main grid (import, export, zero exchange) as well as the bidding strategy (generation and consumption costs) set at the MGCS. The bidding strategy establishes how the power is shared among the different generating units and loads since cheaper generators will be dispatched with more power than more expensive ones and some load may be shed if prices get high enough.

The FuT in TC2, the Transition Function, is the one in charge of connecting and disconnecting the microgrid with the main grid maintaining the system stability within some frequency and voltage ranges. The PoI for TC2 is the test of the MGCS to perform correctly the Transition Function. This function includes planned islanding, unplanned islanding and reconnection testing. The planned islanding considers a situation in which the microgrid operator initiates the islanding process. The unplanned islanded corresponds to the case when some fault in the grid causes the microgrid to automatically disconnect from the main grid. The reconnection case considers the scenario in which the microgrid connects to the main grid (automatic or as a signal coming from the operator). According to the IEEE 2030.7 standard, each test needs to be described according to three main aspects:

- *Initial conditions:* those defining the state of the microgrid at the beginning of the test in terms of topology, generated and consumed power, control objective, etc.
- *Initiating events:* those events that can happen in the microgrid that would produce a certain reaction in the system (changes in load, disturbances, etc.)
- *Measurements:* to indicate the electrical parameters to measure and required values for them

Taking into account the above considerations, the general description of the TS has been particularized for the SuT as indicated in *Table 3*. It has to be noted, that the TS described in this table take into account the limitations of the specific microgrid being tested. This means that from the initially analysed TS only a subset of them is feasible to be executed in the given set-up and for the specific MGCS (ES in HTD). Considered limitations include the lack of enough load to exceed generation, lack of storage devices and the lack of functionality to automatically disconnect from the grid under abnormal grid conditions.

Table 3: Test Specifications based on IEEE 2030.8 requirements

TC	Operating mode	TS	Initial conditions		Initiating event	Target Measures
			PPOI	Bidding strategy		
Dispatch (TC1)	Grid-connected	SS-GCN.LS1	= 0	Equal share	Largest Load Step	Steady state values, dispatch objectives within operator defined requirements and equipment limitations not exceeded
		SS-GCN.LS1	= 0	Unequal share	Largest Load Step	
		SS-GCN.LS2	> 0	Equal share	Largest Load Step	
		SS-GCN.LS3	< 0	Equal share	Largest Load Step	
		SS-GCN.DERT	= 0	Equal share	Trip of large Distributed Energy Resource (DER)	

TC	Operating mode	TS	Initial conditions		Initiating event	Target Measures
			PPOI	Bidding strategy		
	Islanded	SS-ISL.LS1	NA	Equal share	Largest Load Step	
		SS-ISL.LS1	NA	Unequal share	Largest Load Step	
		SS-ISL.LS1	NA	Load shedding	Largest Load Step	
		SS-ISL.LS2	NA	Equal share	Largest Load Step (un-symmetrical)	
		SS-ISL.LS4	NA	Equal share	Largest reactive load	
		SS-ISL.DERS	NA	Equal share	Change of DER output power	
		SS-ISL.DERT1	NA	Equal share	Trip of large DER	
Transition (TC2)	Planned is-landing	PI.PE1	> 0	Equal share	Disconnection signal sent	Frequency / voltage and equipment limi-tations not ex-ceeded during transition
	Unplanned islanding	UPI.T2	> 0	Equal share	Grid outage	Is a microgrid formed
	Reconnec-tion	RC.T1	NA	Equal share	Connection signal sent	Time to recon-nect

5. SUMMARY OF TEST RESULTS AND POTENTIAL IMPROVEMENTS

Fifteen tests have been conducted following the guidelines of the IEEE 2030.8 standard (see *Table 3*) and using the laboratory set up described earlier in this paper. A summary of the results of the tests are described in the following table.

Table 4: Summary of test results

Test ID	Result	Description
SS-GCN.LS1.1	Passed	Since the main grid frequency oscillates around 50 Hz, the primary frequency control produces oscillations in the power exchange at the POI. This causes that the power exchange cannot be brought back to exactly zero by the secondary control after a load step is produced. This is the expected behaviour for the given microgrid set-up. The production share of both inverters follows the applied bidding strategy.

Test ID	Result	Description
SS-GCN.LS1.2	Passed	Same as for SS-GCN.LS1.1 but in this case, some load is disconnected as expected form the applied bidding strategy.
SS-GCN.LS2	Passed	Secondary regulation is able to bring back the power exchange to the scheduled value within the expected tolerance. Deviations from the scheduled value are caused by the primary regulation mechanism.
SS-GCN.LS3	Passed	Same as SS-GCN.LS2
SS-GCN.DERT	Failed	The secondary control does not realize that one of the inverters has been tripped and therefore it is not able to bring back the power at the PoI to the scheduled value.
SS-ISL.LS1.1	Passed	After the load step, both generators increase their power equally following primary regulation control (P vs Fr droop). This causes the frequency to deviate form 50 Hz. After a few second the secondary regulation returns back frequency to 50 Hz (±0.01 Hz). The load share between both generators corresponds to the bidding strategy.
SS-ISL.LS1.2	Passed	Same as for SS-GCN.LS1
SS-ISL.LS1.3	Passed	Same as for SS-GCN.LS1 but in this case, some load is disconnected as expected form the applied biding strategy.
SS-ISL.LS2	Passed	Inverters are able to successfully supply the unsymmetrical load step. Secondary regulation recovers frequency to 50 Hz with the expected load share among generators.
SS-ISL.LS4	Passed	Generators are able to supply the applied capacitive load step. In this case, secondary reacts only for changes in active power.
SS-ISL.DERS	Passed	The primary regulation mechanism adapts the power output of the non-modified inverter according to the generation steps produced in the other inverter. The secondary regulation control brings the frequency back to 50 Hz according to the bidding strategy.
SS-ISL.DERT1	Failed	Some undesired effects are observed: 1) after a few seconds from DER tripping a short consumption peak in the tripped inverter happens and the generation peak on the other inverter is appreciated. This would lead to overpassing the maximum allowed power output of the inverter. 2) The secondary control system is not able to identify the failure of the tripped inverter and therefore it cannot recover frequency to 50 Hz.
PI.PE1	Passed	A small power (3.5 kW) is exported before opening the switch. When the switch opens, the primary regulation adapts the power output of the two inverters and frequency increases accordingly. Secondary regulation is able to bring back frequency to 50 Hz and apply the load share according to the bidding strategy.
UPI.T2	Failed	When the grid simulator is switched off the PoI breaker does not open and the microgrid maintains its connection to the main grid. This behaviour might be dangerous for workers trying to fix the problem at the main grid side. The secondary regulation control does not realize about the failure in the main grid and tries to still follow the power schedule set at the PoI.

Test ID	Result	Description
RC.T1	Passed	When the connection signal is sent, the secondary control increases the frequency (50.05 Hz) in the microgrid in order to produce a fast connection to the main grid. The synchro-check relay closes the switch and the microgrid connects to the main grid. The secondary control system controls the power exchange at the PoI according to the power schedule and bidding strategy.

The tests allowed to identify the following aspects to be improved in the control system:

1. Missing anti-islanding functionality causing the microgrid to remain connected to the main grid in the event of a grid failure.
2. Undesired behaviour under a DER trip event causing:
   - Reverse power flows in the inverters
   - Potential violation of current limits
   - Non-recovery of the nominal frequency in islanded operation mode
   - Non-recovery of the power schedule at the PoI under grid-connected operating mode

As for the potential improvements to IEEE 2030.8, the following can be mentioned:

- The diversity of microgrid configurations and control systems is huge and therefore the definition of specific TCs is left to the test engineer. Although the standard provides a good starting point and guidelines to define specific TS, it would be useful to have examples for typical microgrid configurations and control systems.
- Definitions of target metrics; i.e., response and settling time for measuring results would be improved. For example, for the islanded operating mode it would be useful to use voltage and frequency instead of the power of the generating units.
- The standard mentions “one quarter cycle sample time” in order to “derive quantities such as frequency, rms voltage, [..] power quality (voltage and current harmonic distortions [..]”. Our measurements showed, that a sample time of one quarter of a cycle will not give accurate RMS values or harmonic distortion values. In comparison, the German FGW TR3 “grid connection allowance and electrical characteristics” requires a sample rate ≥ 10 kHz.
- One the other hand, the standard suggests 100 ms minimum sample rate for continuous data collection. Storing only frequency, voltage, current, active and reactive power of just one bus (e.g. PoI) as a single precision float will result in 16 GB of raw data per year. Storing also harmonics will increase this number significantly. This amount of data is in our opinion too much and not practical for field devices.
- It would be good to differentiate between failure levels. During the execution of the tests, the microgrid was able to still operate although some of its functionalities did not perform as expected. A distinction between minor and major failures would allow the identification of critical and no so critical aspects of the control system

6. CONCLUSSIONS AND FUTURE WORK

IEEE 2030.8 provides a good basis for specifying the tests to be done over a MGCS. Using the standard as a guideline, a set of specific tests tailored for a concrete microgrid set-up and control system has been developed. The tests cover the two main functions of microgrid control systems as defined in IEEE 2030.7. These main functions are the Dispatch Function for testing the behaviour of the control system in both grid-connected and islanded operating modes, and the Transition Function for testing the control system in islanded to grid-connected operations and vice versa.

The definition of the tests has been carried out using the ERIGrid HTD procedure. This methodology allowed the representation of specific tests in a clear and consistent way, defining them as independent from the infrastructure to be later mapped as experiments in a certain installation.

The execution of the tests proved to be effective for detecting different aspects in which the MCGS needs to be improved. In the particular case of the tested microgrid, these potential improvements are related mainly to the lack of anti-islanding capabilities as well as unexpected behaviour happening after DER trip events. The main difficulty observed during the test definition phase was related to the fact that since the potential microgrid configurations and control systems may vary significantly, it is rather difficult to define generic TS. Further work would be done by identifying typical microgrid configurations and control systems and trying to specify more concrete TS for those configurations.

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