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Evaluation of the IEEE Std 1547.1-2020 Unintentional Islanding Test Using Power Hardware-in-the-Loop

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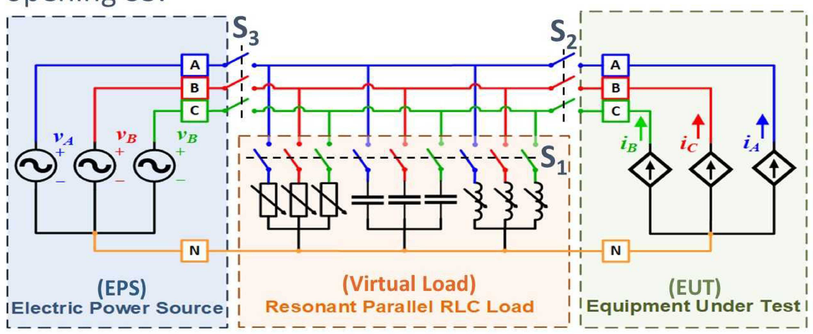
Introduction

Photovoltaic (PV) inverters connected to electrical grids are required to detect and respond to Unintentional Islanding (UI) conditions appropriately. The IEEE Standard 1547.1-2020 specifies test procedures, based on resonant parallel RLC loads, to evaluate the ability of PV inverters to detect and disconnect under UI conditions. This paper proposes a prototype PHIL UI testing console with an HMI and a virtual RLC load to evaluate the IEEE Std 1547.1-2020 UI Cat. B tests. Traditional UI testing procedures rely on physical RLC elements, which are potentially expensive, large, and heat-generating sources.

IEEE Std 1547.1-2020 Cat B. Unintentional Islanding Test

Is a procedure to test the UI capabilities in PV inverters in a controlled environment. In this test the PV inverter (EUT) connected in parallel with a wye RLC load bank and with a utility (EPS). To perform this test active and reactive power between load and the generation should be balanced. The purpose is to verify if the PV inverter disconnects from system when an UI condition is present opening S3.



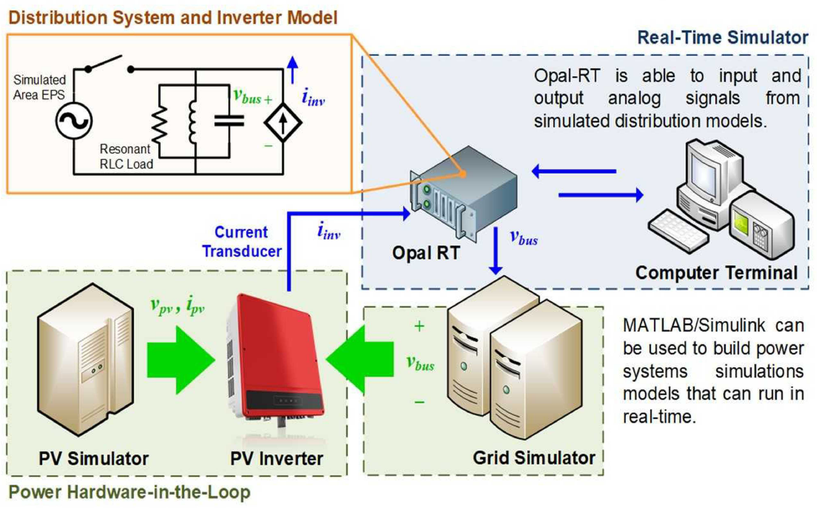
Balanced load Unintentional Islanding Test Matrix for Cat. B

A set of tests that subject PV inverter to different power levels, power factors, and a variety of GSF settings. In an UI testing using PHIL, EPS, switch S3, switch S1, and the virtual RLC load are part of the simulated system running in the Real Time Simulator (RTS). The simulated system interface with the PV inverter through a power amplifier.

Test Case	EUT Power Level (p.u.)		Reactive Power Mode			Active Power Mode Settings		Initial RLC Load (p.u.)			Effective Quality Factor
	P_{EUT}	Q_{EUT}	Mode & setting		Response Time (s)	VW	FW	$P_R+P_L+P_C$	Q_C	Q_L	Q_F
1B	1.00	0.00	Constant Power Factor (CPF)	PF = 1.00	n/a	Default	Default	–1.00	1.00	–1.00	1.00
2B	0.50	0.00						–0.50	0.50	–0.50	1.00
3B	0.90	–0.44	Constant Power Factor (CPF)	PF = –0.90	n/a	Off	LA	–0.90	0.90	–0.46	1.00
4B	0.90	0.44		PF = 0.90				–0.90	0.46	–0.90	1.00
5B	1.00	0.00	Voltage-Reactive Power (VVC)	MA	1	MA	MA	–1.00	1.00	–1.00	1.00
6B	0.50	0.00		Default	10			–0.50	0.50	–0.50	1.00
7B	0.50	0.00	Active Power-Reactive Power (PQC)	Default	n/a			–0.50	0.50	–0.50	1.00
8B	1.00	0.00		MA				–1.00	1.00	–1.00	1.00
9B	0.50	–0.44	**Constant Reactive Power (CQ)**	Q = –0.44	**n/a**			–0.50	0.50	–0.06	1.00
10B	0.50	0.44		**Q = 0.44**				–0.50	0.06	–0.50	1.00

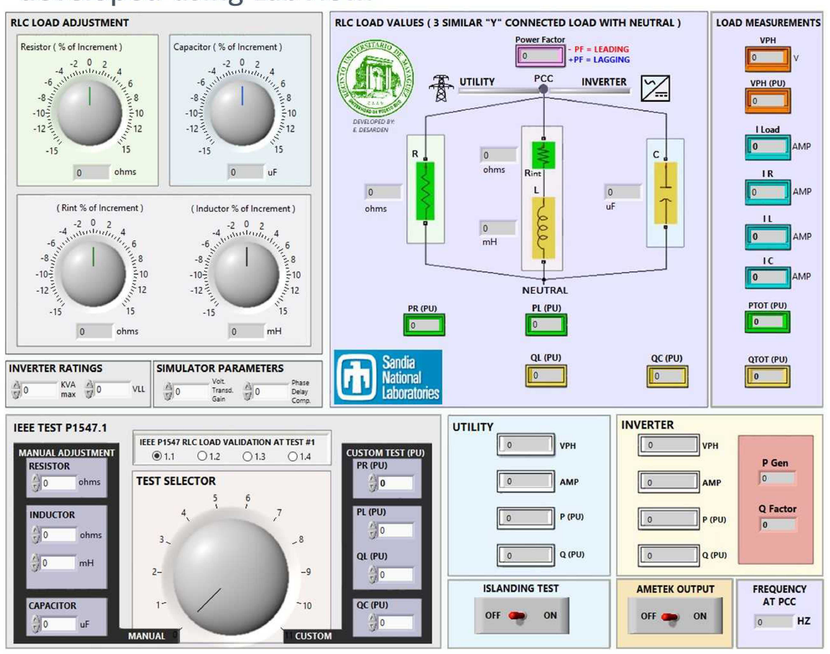
Real-Time Power Hardware-in-the-Loop Setup

Power Hardware-in-the-Loop (PHIL) allows for the testing of a physical device deployed in a simulated environment. This is achieved by connecting an EUT to a power amplifier controlled by an analog signal. A simulation model provides the analog signal for the power amplifier, which is connected to the EUT power terminals. To analyze the system's interaction, the system dynamics connected to a EUT must be modeled accurately.



Human-Machine Interface

The Cat. B UI test can be time-consuming and exposed to errors due to many parameters to adjusted between tests. To simplify the tests' setup process, a virtual instrument was developed. The virtual instrument provides a human-machine interface (HMI), and was developed using LabView.

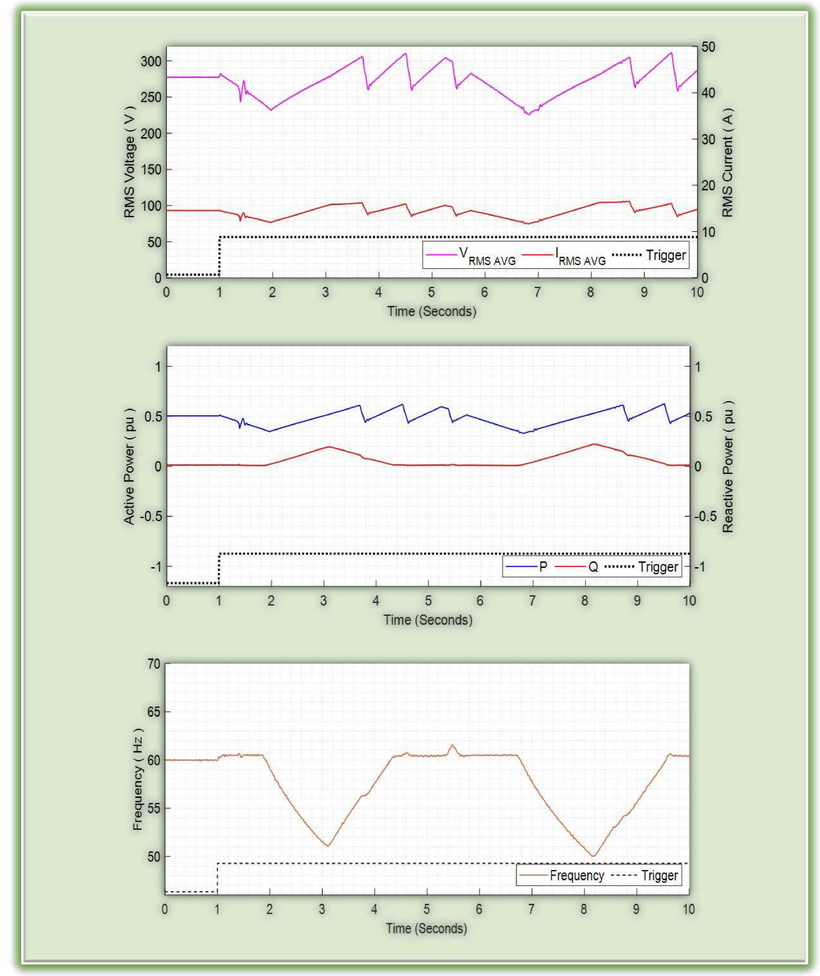


Experimental Results

The test matrix for UI Cat. B was tested in full. Eight of the ten tests ran successfully. Test number eight tripped the PV inverter due to the required VW settings, and test number 10 also caused the PV inverter to trip due to high harmonics detected in the PV inverter's voltage signal. Results for Test Case 6B are shown below.

Test Case 6B

For this test, the UI mode in the PV inverter was set to OFF, to test the inverter's grid support functions used to ride-through voltage and frequency anomalies in the grid. In this test the PV inverter was set to 50% of Rated Power at unity PF, with default Volt-Var setting and Most Aggressive Volt-Watt and Frequency-Watt setting. Test is successful if PV inverter sustain the Islanded condition for at least 10 seconds.



Conclusion

The implementation of the IEEE Std 1547.1-2020 UI Cat. B tests using RTS, PHIL, and the HMI technique could be cost-effective and could produce good results.

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