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Distributed Energy Resource System Validation According to the IEEE 1547-2018 Standard Current Distortion Limits

Marko Dimitrijević[a] and Milutin Petronijević[b]

[a]*Faculty of Electronic Engineering, University of Niš, Niš RS, marko.dimitrijevic@elfak.ni.ac.rs*
[b]*Faculty of Electronic Engineering, University of Niš, Niš, RS, milutin.petronijevic@elfak.ni.ac.rs*

Abstract: The global increase in energy demand, as well the need to reduce CO_2 emissions, have led to increased scientific and commercial interest in renewable and distributed energy resources (DER) and their integration into traditional electric power system (EPS). The traditional EPS is designed for power delivery and consumption, but not for generation and energy storage at end-user level. This integration is a subject of perpetual research and study, and certain standards are imposed in order to regulate it. The IEEE 1547-2018 standard defines specifications for interconnection and interoperability of DERs within EPS. In this manuscript, the validation of one DER implementation from the aspect of current distortion and direct current injection will be presented. The measurements were performed using the virtual instrument for the characterization of nonlinear loads, which was modified in accordance with the IEEE 1547-2018 standard.

Keywords: Distributed energy resources, Electric power system, Current distortion.

1. Introduction

Growing awareness of global warming and increasing energy needs have initiated scientific, as well commercial interest in renewable energy sources (RES). The first applications of RES, especially photovoltaics, were autonomous systems located in remote areas where it was not possible to connect to the electric power system (EPS). Another type of RES system is a system that is connected to a microgrid or public power grid. These systems vary in output power from residential (2 – 10kW) to solar power plants (up to 10GW) [1].

In the last decade, installations of grid-connected RES systems are increasing due to several advantages over stand-alone systems. Those systems are usually referred as distributed energy resources (DER). However, an implementation of one DER is enabled by means of power converters, implemented using power electronics and control software [2]. Therefore, DERs must meet voltage and current quality criteria, and fulfill appropriate requirements for integration into the power distribution grid.

The IEEE1547-2018 standard [3] prescribes power quality issues, which can be classified into four categories: reactive power capability and voltage/power control requirements, limitations of voltage fluctuations – flicker, DC current injection limit and current distortion limitations. In order to test and validate one DER system, one must perform a set of measurements using different instruments, such as power quality meter, flickermeter, power meter and true RMS ammeter with DC coupling. Furthermore, the measurement results must be manually summarized into a complete validity report. Therefore, the whole process is expensive and time consuming.

In order to facilitate validation and testing, a unique, integrated distributed energy resource testing and validation system is developed. The system is based on virtual instrumentation paradigm, capable of performing all measurements required by IEEE 1547-2018 standard, using only one measurement setup. The system is capable of generating complete measurement report, including validation assessment according to the standard. It consists of connection circuit with current sensors, acquisition device for voltage/current acquisition and virtual instrument for analysis, data presentation and reporting. In this proceeding, the system structure, as well operations and measurements related to DER currents, i.e., DC injection and current distortion are presented. These limitations, related to current distortion and DC injection, are summarized in Table 1.

The paper is organized as follows: in the second section the system for DER testing is presented. In third section, measurement setup and results are discussed. Forth section concludes the manuscript.

Table 1. IEEE 1547-2018 DC current injection and current distortion limitations

Harmonic order	DC	2	3	4	5	6	7	8	9	10
% (I_{rated})	0.5	1	4	2	4	3	4	4	4	4
Harmonic order	11	12	13	14	15	16	17	18	19	20
% (I_{rated})	2	2	2	2	2	2	1.5	1.5	1.5	1.5
Harmonic order	21	22	23	24	25	26	27	28	29	30
% (I_{rated})	1.5	1.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Harmonic order	31	32	33	34	35	36	37	38	39	40
% (I_{rated})	0.6	0.6	0.6	0.6	0.3	0.3	0.3	0.3	0.3	0.3
Harmonic order	41	42	43	44	45	46	47	48	49	50
% (I_{rated})	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

2. The system for DER testing and validation

2.1 Acquisition subsystem

The system for DER testing and validation consists of two key parts: acquisition subsystem and virtual instrument for analysis and data presentation. The acquisition subsystem consists of a connection circuit with current sensors, acquisition modules and data interface (Figure 1). There are two current ranges available, supporting measurements of up to 5A and 50A. A higher current range is achieved with three CSNC241-500 Hall effect sensors, chosen for good accuracy when measuring the DC current component. Hall's effect sensors require a separate power source, DC and temperature calibration, as well phase compensation is necessary.

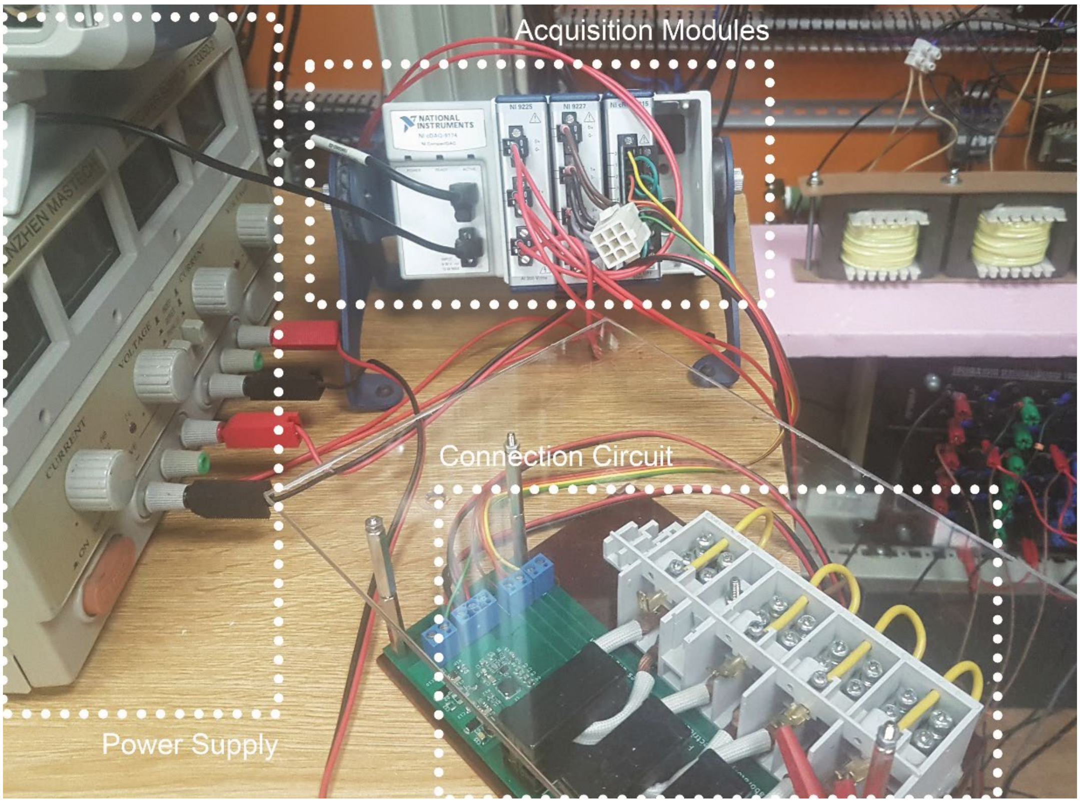


Figure 1. Acquisition subsystem

The sensor outputs are connected to the National Instruments NI9215 acquisition module [4]. The module is equipped with three channels capable of simultaneous voltage sampling with 16-bit resolution, 100kS/s sampling rate and 250Vrms channel-to-earth isolation. Voltages are measured directly using the National Instruments NI9227 acquisition module [5]. NI9227 possesses four channels for simultaneous current sampling with 24-bit resolution, 50000 samples per second sampling rate, and 250V rms channel-to-channel isolation.

2.2 Virtual instrument for data analysis and reporting

The virtual instrument is implemented using the LabVIEW developing package (Figure 2) [6]. It performs following tasks: acquisition control, calculation of current harmonic amplitudes and data logging and saving.

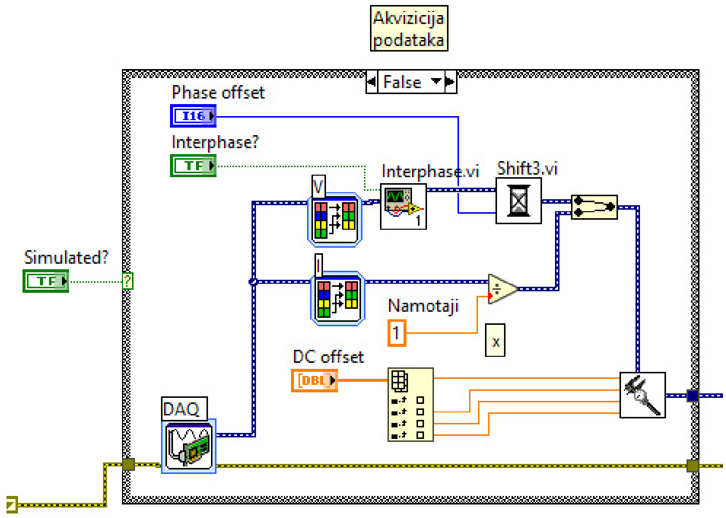
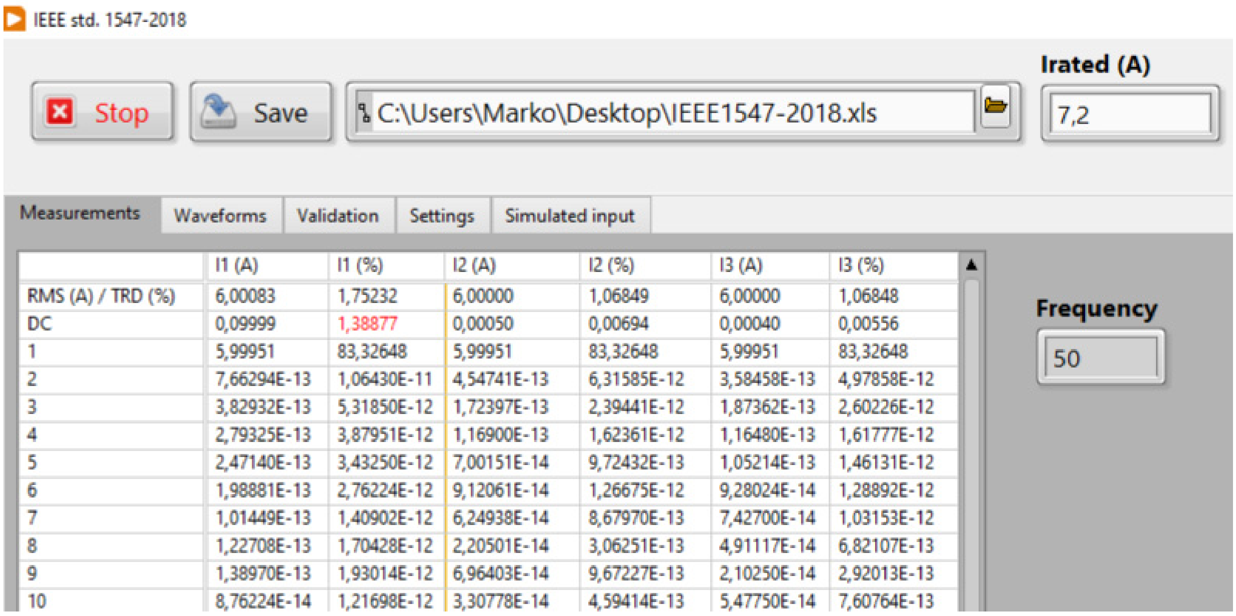


Figure 2. Virtual instrument for DER testing and validation – part of the graphics code whose function is acquisition control, DC offset compensation and signal phase correction

The virtual instrument key function is to act as user interface of whole system (Figure 3). The user interface allows setting various parameters, such as acquisition parameters, DER rated current, simulated input parameters, path of the file containing the validation report, etc. The results of all measurements as well as the validation assessment of the system under test are also displayed in the user interface.



	I1 (A)	I1 (%)	I2 (A)	I2 (%)	I3 (A)	I3 (%)
RMS (A) / TRD (%)	6,00083	1,75232	6,00000	1,06849	6,00000	1,06848
DC	0,09999	1,38877	0,00050	0,00694	0,00040	0,00556
1	5,99951	83,32648	5,99951	83,32648	5,99951	83,32648
2	7,66294E-13	1,06430E-11	4,54741E-13	6,31585E-12	3,58458E-13	4,97858E-12
3	3,82932E-13	5,31850E-12	1,72397E-13	2,39441E-12	1,87362E-13	2,60226E-12
4	2,79325E-13	3,87951E-12	1,16900E-13	1,62361E-12	1,16480E-13	1,61777E-12
5	2,47140E-13	3,43250E-12	7,00151E-14	9,72432E-13	1,05214E-13	1,46131E-12
6	1,98881E-13	2,76224E-12	9,12061E-14	1,26675E-12	9,28024E-14	1,28892E-12
7	1,01449E-13	1,40902E-12	6,24938E-14	8,67970E-13	7,42700E-14	1,03153E-12
8	1,22708E-13	1,70428E-12	2,20501E-14	3,06251E-13	4,91117E-14	6,82107E-13
9	1,38970E-13	1,93014E-12	6,96403E-14	9,67227E-13	2,10250E-14	2,92013E-13
10	8,76224E-14	1,21698E-12	3,30778E-14	4,59414E-13	5,47750E-14	7,60764E-13

Figure 3. Virtual instrument user interface. The simulated input is used in order to test its functionality: The DC component of the current I_1 is deliberately set above the value allowed by the standard, which is indicated in red in the table on the user interface

3. Measured results

3.1 Measurement setup

In the course of this research, thorough laboratory measurements were performed on a microgrid laboratory prototype with a number of commercial, as well as purpose-built single-phase and three-phase grid inverters. Grid inverters are powered from programmable DC source ITECH model IT6000C, capable of emulating the solar panels and battery energy storage. The developed virtual measuring system is purposely prepared for the validation of steady-state performances of the new grid inverter control algorithms. At the beginning of the test, the results obtained from this measuring system were compared with the measuring results collected by the high-precision reference instrument ZES LMG-450 [7]. Matching of the values for current harmonics measured with measuring system and the reference device, along with the fact that measuring system is designed to automatically provide reports on compliance with IEEE 1547-2018, gives a significant advantage when testing grid inverters.

3.2 Results

As an illustration, Table 2 shows the results of measuring the mains current (I_3, spectrum shown on Figure 4.) and the inverter output current (I_1) of a laboratory mains inverter with an LCL filter on the interface side of the mains.

Table 2. DC component, TRD and current harmonics up to 50th order, for I_{rated}=7.2A and power equal to 80% rated value

	I_1(A)	I_1(%)	I_2(A)	I_2(%)	I_3(A)	I_3(%)		I_1(A)	I_1(%)	I_2(A)	I_2(%)	I_3(A)	I_3(%)
TRD		1.74		2.97		3							
DC	0.03	0.38	0.01	0.11	0.03	0.44	26	0	0.02	0.01	0.1	0.01	0.08
2	0.03	0.35	0.03	0.38	0.02	0.32	27	0	0.01	0	0.07	0.01	0.08
3	0.02	0.34	0.01	0.19	0.01	0.15	28	0.01	0.08	0.01	0.07	0.01	0.13
4	0.01	0.13	0.01	0.2	0.02	0.28	29	0	0.01	0	0.05	0	0.06
5	0.03	0.44	0.06	0.87	0.07	0.94	30	0	0.04	0	0.04	0	0.03
6	0.03	0.38	0.02	0.32	0.05	0.68	31	0	0.02	0	0.02	0	0.05
7	0.04	0.62	0.05	0.67	0.05	0.71	32	0	0.03	0	0.02	0	0.04
8	0.01	0.07	0.01	0.08	0.01	0.16	33	0	0.02	0	0.01	0	0.05
9	0.01	0.07	0	0.03	0.01	0.11	34	0	0.04	0	0.02	0	0.04
10	0.02	0.21	0.02	0.26	0.03	0.46	35	0	0.02	0	0.01	0	0.03
11	0.02	0.26	0.03	0.38	0.04	0.57	36	0	0.02	0	0.02	0	0.02
12	0.04	0.5	0.03	0.38	0.05	0.7	37	0	0.02	0	0.01	0	0.03
13	0.03	0.38	0	0.04	0.03	0.41	38	0	0.03	0	0.01	0	0.01
14	0.05	0.63	0.02	0.28	0.05	0.73	39	0	0.02	0	0.01	0	0.02
15	0.02	0.21	0.02	0.26	0.03	0.4	40	0	0.03	0	0.01	0	0.02
16	0.03	0.43	0.01	0.11	0.03	0.46	41	0	0.01	0	0	0	0.02
17	0.01	0.1	0.02	0.24	0.02	0.34	42	0	0.01	0	0.01	0	0.01
18	0.02	0.29	0.01	0.1	0.02	0.23	43	0	0.02	0	0.02	0	0.02
19	0.04	0.54	0.01	0.2	0.05	0.73	44	0	0.02	0	0.02	0	0.01
20	0	0.02	0.01	0.16	0.01	0.14	45	0	0.01	0	0.01	0	0.02
21	0.01	0.21	0.01	0.09	0.02	0.27	46	0	0.01	0	0.01	0	0.01
22	0	0.02	0	0.06	0	0.04	47	0	0.01	0	0.01	0	0.01
23	0.01	0.1	0	0.01	0.01	0.13	48	0	0	0	0.01	0	0
24	0	0.02	0.01	0.07	0.01	0.1	49	0	0.02	0	0.02	0	0.01
25	0.01	0.13	0.01	0.1	0.01	0.17	50	0	0	0	0.02	0	0.01

The measured results are for an inverter with 7.2A nominal current and with active power equal to 80% rated value. By examining measured values for DC component, individual harmonics and TRD factor, one can conclude that DER under test satisfies limitation of current distortion criteria and DC current injection prescribed by IEEE 1547-2018 standard.

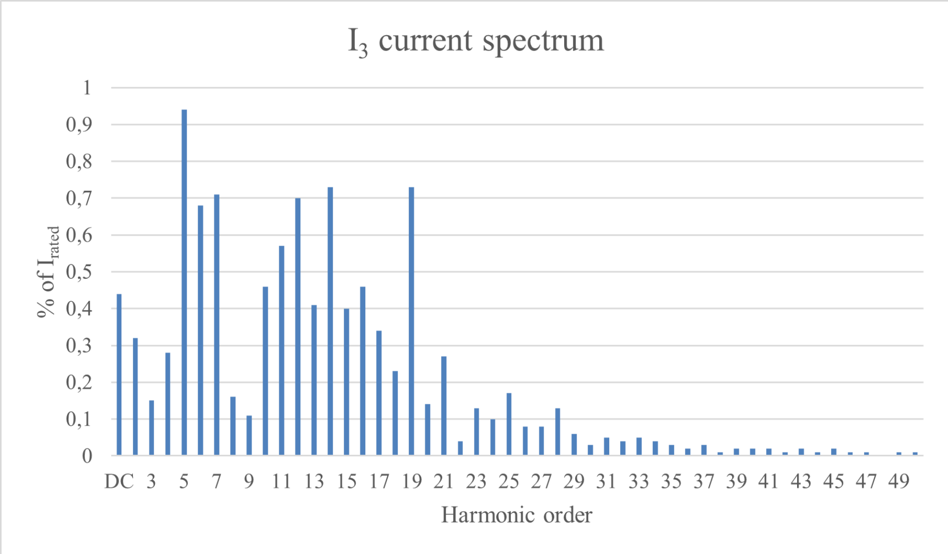


Figure 4. Current spectrum of I_3. Individual harmonics are presented as percent of I_{rated}.

4. Conclusion

In this proceeding, the microgrid measuring and validation system based on virtual instrumentation paradigm was presented. For the purpose of this research, a set of measurements related to output currents were performed on the laboratory prototype microgrid, and compared with reference instrument. Described system provided accurate results, and microgrid prototype was validated according to IEEE 1547-2018 standard current distortion limitation and DC current injection.

In further development, other aspect of IEEE 1547-2018 standard, such as limitation of voltage fluctuations, will be incorporated into system operation capabilities.

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