Research Laboratory for Monitoring and Analysis of Power Quality in Power Distribution Grids

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Abstract: - INCESA, the University of Craiova's project financed through European grants, has already initiated large projects on topics such as smart grids, energy storage, transmission and distribution system, renewable energy. The research projects on these topics are conducted specifically in the framework of the INCESA's Smart Grids Research Laboratory (SGRL). The aim of this paper is to introduce the infrastructure of SGRL and the operational characteristics and monitoring facilities of its units. The results of a study case are also presented in order to demonstrate the capabilities of the hardware and software laboratory infrastructure suitable for comprehensive power quality assessments personalized for industry applications (power distribution grids facilities).

Key-Words: - smart grid, research unit, renewable source, testbed, power quality

1 Introduction

The present trend of dispersing the power production by using the renewable energy sources (RES) together with the increasing of the active consumers connected to the electrical power grids ask for a different approach to the operation of the power system as a whole, as well as of its component distribution grids. This context sustains the developing of the Smart Grid concept, which interfaces the producers, consumers, and prosumers while a reliable and qualitative electricity is supplied [1, 2].

Consequently, a research and industrial community organized through regional interactive platforms has been developed in order to answer to the needs of the smart grids research and innovation actors and help them to find proper research partners. In this area, the universities and research units can mainly contribute to develop and integrate the Smart Grid research infrastructures.

In this framework, the University of Craiova's Research Hub for Applied Sciences INCESA aims not only to develop technical concepts for industry partners, but also to support the industry activity through collaborative or contract-based research or by teaching and educating researchers and engineers in the field of smart technologies. INCESA has already initiated large projects on topics such as smart grids, energy storage, transmission and distribution systems, and renewable energy. The research projects on these topics are conducted specifically within the INCESA's Smart Grid Research Laboratory (SGRL).

The vision of this laboratory is to be recognized as a regional research and innovation center dedicated to solving the urban and industrial energy challenges. In addition to Research and Development, SGRL shall initiate demonstration projects facilitating the innovation and commercialization of groundbreaking energy solutions. The facility shall also operate as an incubator for encouraging innovators to bring new producible ideas for research and commercialization. SGRL is interested or already involved in projects where it collaborates with other universities or industrial partners.

The aim of this paper is to introduce the infrastructure of SGRL and the operational characteristics and monitoring facilities of its units.

As a particular study case, the possible impact of grid-connected PV systems on power quality (PQ) in distribution networks is studied so that feasible solutions before real-time and practical implementations can be provided further. Some results obtained from monitoring the laboratory PV plant over a standard monitoring interval of 1 week are presented and analysed.

2 The Smart Grid Laboratory of INCESA

INCESA (Research Hub for Applied Sciences of University of Craiova) is currently one of the largest Romanian organizations of applied research. It was designed to support the regional evolution of R&D infrastructure and activities according to the institutional strategy of the University of Craiova that will enhance the multidisciplinary research capacity and integration to the European research networks.

The Smart Grid Research Laboratory, as one of the 13 research units of INCESA, is developing activities as research, innovation, testing and training in the field of the classical power systems and new smart grid technologies.

Assessing these challenges generally requires a number of tests and experiments performed initially in dedicated research infrastructure and laboratories, and developed further as larger scale demonstrators.

2.1 The structure of Smart Grid Laboratory

The laboratory is a multifunctional unit simulating a reduced scale 400 V 3-phase power system. The main components of this laboratory are as follows:

2.1.1 The hardware & software components

A. Power supply system

This system includes the public network supply input bus (connected through underground cable to 800 kVA MV/LV substation), as well as on the renewable sources units with the following components, as in Fig. 1:

- 6 kW photovoltaic panels system (Polycrystalline cell, 3-busbar technology with controlled solar grid inverters Sunny Boy 2500 with Sunny remote control);
- Energy storage units (solar batteries Solar 12V-250 Ah lead-acid type) with controlled bi-directional converters;
- Controlled AC Loads with AC-DC-AC back-to-back converters;
- Distribution Management System (DMS) including hardware and software;
- Remotely accessed weather station (Delta-T).

B. The metering infrastructure

It has the following components:

- Power meter system (A-class MAVOWATT 30&240 power meters, MI 2829 Metrel, Fluke 435, CA 8335 Chauvin Arnoux);
- Infrared Thermovision System (CA 1888 - Chauvin Arnoux);
- Intelligent cable and faults location system (vLocPro2 SEBA KMT);
- Remotely data acquisition and transmission system (with technical specification according to the requirements of the national authority for energy regulation).

C. The software library for design, simulation and analysis of power systems

It is composed of the powerful software tools (packages) specialized for design, modeling and analysis of power systems/networks [3, 4]:

- Paladin DesignBase v5.0 SP.3
- SMART FLOW v.2.0 (incl. EUROSTAG)
- PSCAD 45
- EMTP RV 3.3
- NEPLAN 5.5.3
- ETAP 14.1.0
- PowerWorld v18
- PQView
- Engineering Base Electrical
- Matlab/Simulink (Power system library)

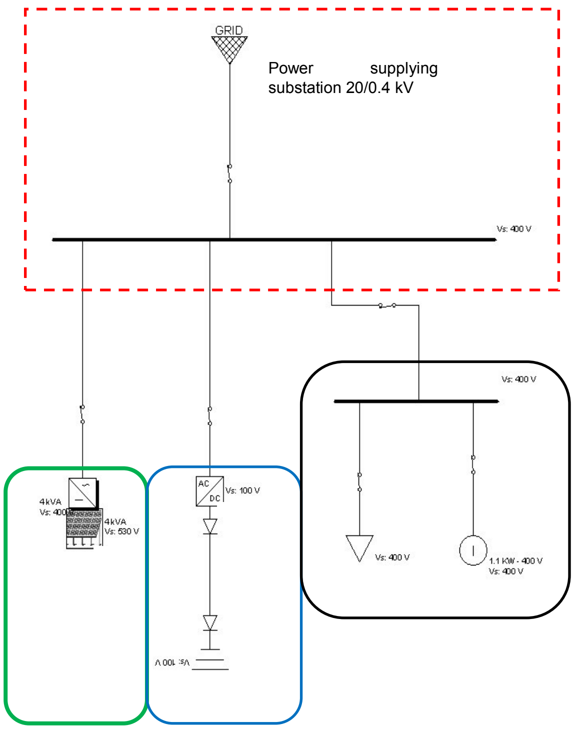

Fig. 1. Configuration of the power supplying network of SGRL

2.1.2 Laboratory projects and research areas

At SGRL up to 3 main research areas are approached since now: Power grids management, Generation and distributed energy resources (GDER), Power market.

Grid Management

It refers to all the systems, applications and actions to control and manage the power grid in an efficient and highly automated way. It refers also to the tools for extracting information from the monitoring and control systems in the physical grid.

The main topics covered in this area are: optimization of power flows, transitory analysis of power grid and its components, advanced control systems, energy efficiency, voltage control and reactive power, microgrids, power quality, reliability, diagnosis tools, data analysis for grid management.

Generation and distributed energy resources

They refers to all generators connected to the transmission grid (dispatchable or not controllable), as well as electrochemical sources and storage units connected to the distribution system.

The topics considered are the following: wind energy, PVs, hydro fuel fell, conventional power plants with the following research objectives: integration of renewable energy sources, considering forecasting, control, PQ, and energy management strategies.

Power Market

It refers to all the activities related with the impact of the smart grids on the electricity markets.

The topics considered are the following: technology market barriers in the Smart Grids, market structure, new regulation schemes for deregulated actors, novel trading schemes, impact of RES integration on electricity prices, tariffs.

The SGRL provides an testbed for pilot testing and demonstrations for industry partners. According to the previous stated research targets, the following smart grid projects are developed and implemented within SGRL:

Assessment of microgrid operation

The laboratory's microgrid structure enables the study of the power grids operation functions as: load forecasting, load management, operation and energy storage optimization, distributed generation management.

Power Quality Studies

The impact of the different electromagnetic disturbances sources can be studied, measured, and analyzed in SGRL. The studies are undertaken to quantify the PQ parameters and their cumulative effect at various levels of generation [3]. The available hardware and software components provide the functions of an advanced PQ Data Management and Analysis System.

Advanced metering

A subunit of SGRL is organized as an advanced metering infrastructure test facility. This is explored as solution for improving the system reliability and distribution system performance [3].

It includes a small integrated unit with smart meters, communications networks, and data management systems that enables two-way communication between utility simulator and building's customers. The topics considered here are the following: billing, customer information, equipment installation and configuration, energy and PQ monitoring, demand response.

Testing Platform

Within SGRL, in collaboration with laboratory of physical-chemical characterization and material testing, some test procedures for products in the smart grid area can be developed, being of interest for utilities and energy users: PV cell/panels, electrochemical generation/storage units.

Training/Education

SGRL can host training/instruction sessions on the smart grids' topics. This laboratory allows the formation of the Master and PhD students, as well as the training of highly qualified personnel specializing in smart grids contributing to regional economy.

3 Tests and PQ analysis performed within SGRL

Tests, computer simulations and analysis are performed within SGRL in order to study the effect of renewable generation sources and other forms of distributed generation and loads over the electric power grid which they are connected to.

In this section we outline the configuration and parameters' settings of the hardware and software laboratory's testbed used for developing the projects of grid management after RES integration. The analysis and resulting reports describing the system operation are also presented.

The Renewable Power Generation Unit of SGRL (RPGU) is designed for research studies related to distributed generation such as the effects of PV sources connection to LV network, impact of source operation on the network and loads operation, as well as the influence of the network on the source. A special category of investigations is made on this PV grid-connected system regarding the PQ.

These issues can be handled in according to regulatory standards as the national technical code and performance standard of the (service of) power distribution.

The infrastructure of RPGU uses the following

facilities and tools, as are presented in Fig. 2:
- 5.88 kW rated PV system;
- 12V-250 Ah lead-acid type solar battery system;
- Measurement and data transmission system;
- PQ data management and analysis system.

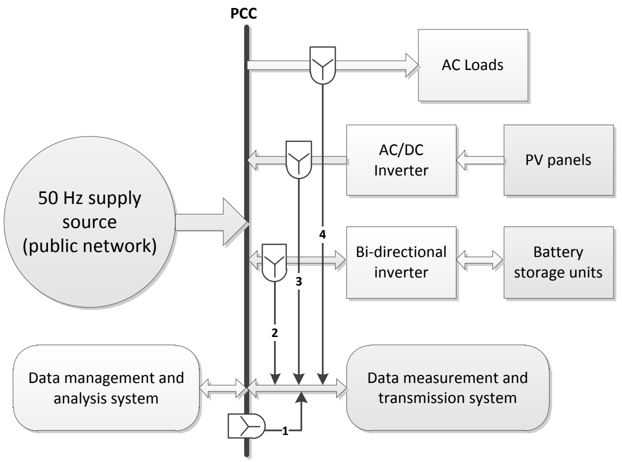

Fig. 2. Schematic of AC-connected hybrid energy system of SGRL

3.1 PV System

PV system is a rated power of 5.88 kW one with 24 x photovoltaic module Conergy PJ 245P, series interconnected, suitable for island and having the following specification:

- Placement: on the roof platform of INCESA's building southwards exposed;
- Polycrystalline cell, 3-busbar technology;
- Nominal ratings under standard test condition:

Max. power	≥ 245 W
Max. voltage	29.7 V
Max. current	8.25 A
Efficiency	15.09 %

- 1 x Sunny Boy 2500 inverter for connecting the PV to LV supplying grid of INCESA's building, with the following technical data:

Max. DC power	2600 W
Max. DC voltage	700 V
Max. input current	15 A
AC nominal power (230 V, 50 Hz)	2500 W
Max. efficiency	96.3 %

3.2 Storage System

It has the following components:

- 8 x BSB solar battery Solar 12V-250 Ah lead-acid type, operating as energy storage units: 2 parallel circuits of 4 serial connected units supplying 48 V/branch, 500 Ah totally.
- 1x single-phase bi-directional inverter SI 6.0H-11, for connecting the battery to LV supplying grid of INCESA's building, having the following technical data:

Rated AC output power	4600 W (cosφ =1)
Rated AC output current	20/120 A
Voltage AC	230 V/202...253 V
Voltage DC	48/41...63 V
Max. efficiency	96.0 %

3.3 Measurement and data transmission system

The system structure and characteristics are in accordance with the standard requirements stated in Order 74/2013 of National Energy Regulation Authority (ANRE) for A3 type certification of the renewable generation units. The system includes basically:

- A-class MAVOWATT 240 power meters with GPS transmission data system connected to the point of interest as in Fig. 2;
- Complex remote acquisition and data transmission system with AOIP data acquisition unit, 3 x Sineax DM5S, AC programmable P/Q/U transducers, 1 x Sineax F534 AC frequency transducer, 1 x EAC-I 500 variable frequency generator, as is given in Fig.3;

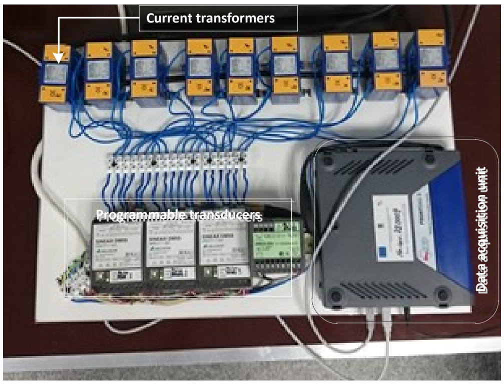

Fig. 3. Connection configuration of the remote data acquisition and transmission units

- PQView software for management and analysis of the energy and PQ parameters [5].

4 Study case - PQ analysis and report

The voltage sag is actually the most common PQ issue regarding voltage variations affecting the electrical equipment of the present power distribution grid's users.

Nevertheless, the flicker level and the harmonic content are also significantly counted with high technical impact on the PQ level at the grid connection bus of the RES.

By using PQView, a complex software system for the management and analysis of PQ the above characteristics were examined for the 6 kVA PV micro-power plant (PVPP) connected to the 0.4 kV grid of the INCESA's SGRL. The PQ analysis is based on the outputs provided by the local measurement and transmission data system (in accordance with Std. CEI 6000-4-30 specifications).

For the studied configuration, the power meter and data acquisition system send the data to a virtual Energy Management Center (EMC) operated by PQView [5]. This one can compute the power grid status for up to 50 surveillance sites and generate professional reports. The PQView system ensures the continuous updating and analysis of PQ characteristics such as system average RMS-variation frequency index (SARFI), voltage distortion THD, voltage imbalance, and flicker severity Plt.

4.1 Measurement conditions

The study aims to evaluate those performance and PQ parameters influencing the proper operation of a power distribution grid with RES incorporated and supplying large diversity of loads. It is part of a larger project to be implemented in the grid of the local power distribution operator.

Synchronized measurements were performed at the Point of Common Connection PCC of the SGRL's micro-grid testbed, for the 4 points of interest (PoI) placed as in Fig. 2: (1) public supplying network bus of SGRL; (2) connection branch of the battery storage inverter; (3) connection branch of the PVPP's inverter; (4) connection branch of the laboratory consumers. The data were acquired by using PQ monitors of MAVOWATT Technology, as well as by the remote data acquisition and transmission unit, with error pursuant to Class A of the EN 61000-4-7 standard. They are further transferred to the server of Data management and analysis system PQView, where they are organized in a PQ database and analyzed.

Since the PQ parameters have rather a random behaviour, the registered data are statistically processed. The information about the CP95% of the PQ parameters is provided at the PoI's during a minimum interval of 1 week (in our case 10.05.2017 through 18.05.2017). Their compliance with the Romanian Performance Standard of Power Distribution Service (PSPDS) [6] (respectively EN 50160 Std.) is also checked, according to values in Table 1.

For all the four PoI located in SGRL's testbed, the measurement data were loaded in PQView database and their validity was checked, the suspicious and discrepant values being filtered. The valid data were further provided toward PQView analysis module (PQDA), where the general power evolution of the sites was analysed and a statistical analysis of the PQ parameters was performed.

Table 1. The supply voltage characteristics in public LV and MV according to EN 50160

Voltage parameter	Permissible deviation ranges
Voltage magnitude variations	±10% for 95% of week, mean 10 minutes RMS values
Rapid voltage change (Flicker) Plt	up to 1 for 95% of week
Supply voltage unbalance	up to 2% for 95% of week, mean 10 minutes RMS values
Harmonic voltage	VTDF ≤ 8% for 95% of week

4.2 The Power Quality Summary Report

The following reports are generated by using PQView software. The behavior of PVPP system, storage unit (inverter), complex load and the AC supplying system can be described based on the histograms of steady-state logs loaded in the PQView database (here voltage, THD, Plt) – see samples for PoI (1) in Fig.4.

The advanced PQ event monitoring in PoI no (4) with complex loads is going to supply information to determine the sources of disturbing events as sags, swells, harmonics and flicker in the LV networks. The complex load includes residential and office type consumers: 2.8 kW fluorescent lighting system, group of non-linear loads (supplied power of 3.2 kW) including television, personal computers, refrigerator, and air conditioner.

Actually, the recorded measurements of the electrical values describe the characteristic of the complex load supplied either from PVPP system, or by the battery storage units, during the surveillance period in generally, and daily in particularly. The analysis of the 4 recordings performed on the micro-grid branches outlined the results as in the Table 2.

Table 2. The results of recordings in the testbed (10-minute 95%values)

PoI	Voltage RMS		Harmonics (THD %)		Flicker severity (Plt)	
	V	Std. compl	%	Std. compl		Std. compl
1	239.9	Yes	3.5	Yes	0.4	Yes
2	230.7	Yes	1.2	Yes	0.3	Yes
3	231.1	Yes	4.4	Yes	2.1	No
4	230.0	Yes	4.2	Yes	1.1	No

By creating timelines to combine the event data with the steady state logs, useful information about the nature of the events can be provided. For instance, the voltage magnitude is maintained in the permissible deviation range (216…264 V) for all PoI's, (PC95% 21.285 kV). A small range of voltage distortion was registered, as well with a CP95 of THD under 2% for all PoI's (within PSPDS and EN 50160 Std. limit of 8%). On the other hand, the registered long-term flicker (Plt) outlined high daily variations corresponding to a CP95 value of 1.1 outside of the allowable range within 1 unit. The over-unit CP95 data indicate problems related to the voltage fluctuations, with disturbing consequences on the level of customer's sides.

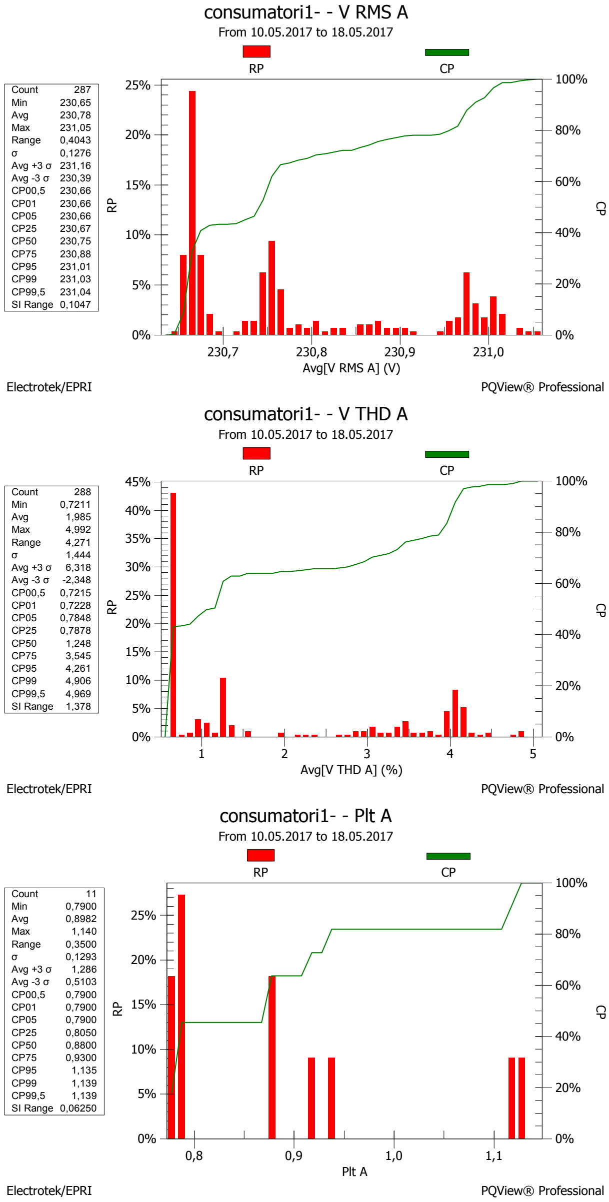

Fig. 4. Histogram of PQ parameters in PoI (4): phase RMS, phase voltage THD, phase Plt

5 CONCLUSIONS

Since nowadays the penetration of distributed generation is highly anticipated, this evolution is likely to present the power distribution grids operators with high number of technical impacts related to PQ. Consequently, impact studies should be performed based on data provided by monitoring sessions in the strategic sites of the network. Since the PQ monitoring is performed in a non-satisfactory number of sites, a comprehensive analysis can be supported by a PQ management and analysis system and laboratory test and analysis for predicting of the real systems' behaviour.

The paper present the processing capabilities of the Smart Grid laboratory of INCESA dedicated to the industry projects of management and analysis of the PQ data. A PQ analysis was performed as study case for the laboratory micro-grid with RES and complex loads connected. The PQ analysis was performed against the standard specification. The information can be further used as reference for reliability studies and operation prediction of this network. The recommendations for mitigation and PQ improvement strategies for both the power system and customer facilities can be developed, too.

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