LABVIEW DESIGN AND SIMULATION OF A SMALL SCALE MICROGRID

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The operating conditions of the National Power System require new solutions to be undertaken for achieving continuity of power supply. Thus, worldwide, two research directions have been proposed: the microgrid structure and the DC low voltage supplying structure.

The paper presents the integration of renewable energy sources into a mixed microgrid in order to ensure the users' continuous power supply. The microgrid modeling was achieved for a real user. In this location, an extended monitoring campaign of the meteorological parameters and the electric power forecasting, has been pursued.

Keywords: microgrid, LabVIEW, renewable energy sources.

1. Introduction

Recently, a new solution for local energy distribution within existing power systems has been proposed: *microgrids*.

The microgrid is essentially an active distribution network standing for a conglomerate of distributed generation units and different loads at the low voltage level (including the storage elements) as well as the final users. The technical features of a microgrid make it suitable for supplying power to remote areas as well where supply from the national grid system is uneconomic for several operation scenarios. In addition, the microgrids can be designed and implemented much faster than the classic version of the connection to the local distribution system and therefore are ideal for mobile applications (military as well).

According to today's experience [1-10], and publications, there are outlined four major microgrid market segments: building, (residential, commercial

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and industrial), campus/community (residential, commercial and industrial), cities (Smart Cities) and military bases.

For civil applications, microgrids are LV network sections dedicated to supply electrical energy to the users in small communities (residential, schools, universities, shops) and include local generation units which are in most cases based on renewable energy resources. The main goals of integrating distributed generation [11-15] in such MV and LV networks are, beyond the low cost of the primary energy: attaining an increased reliability, higher levels of security, and protection for both users and equipment. To be underlined here, is that the existing regulations, at least in Europe, prevent islanding, i.e. the separation of DG units from the faulty energy system. The microgrid is on the contrary providing a sustainable operation of DG units, after fault occurrence in the main grid, thanks to the dedicated control algorithms.

In order to attain a reliable operation of microgrids, there are firstly to be solved several technical, economical and regulatory issues: intermittent renewable-based distributed generation, non-controllable generation, unbalanced energy mix (only a few primary resources are available), the lack of standardization, the not-adapted regulations etc. These are world-wide research topics for microgrids area and the potential solutions have to be tested on the way.

A key characteristic of a microgrid is that it is designed to meet all the requirements of the electric power system while in the same time, it should be able to provide different levels of reliability, quality of service and power quality depending on the importance of the end users.

The operation of microgrids can be achieved either at direct voltage (DC microgrids), alternating voltage (AC microgrids) or they can include hybrid structures - hybrid microgrids (with separate DC and AC rings bi-directionally interconnected by static converters).

The current microgrids can operate either in parallel with the national electric power systems, or islanded, so that the control, protection and energy management can cover both operating modes. Thanks to the capability of offering higher levels for power quality and reliability, a large number of users will adopt power supply solutions based on advanced technology and power electronics in order to minimize voltage sags, interruptions and other power quality disturbances.

The paper presents the design and simulation of a small scale microgrid by using the LabVIEW software, due to the fact that this programming environment is applicable in many scientific and technical areas, from the engineering field. LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a graphical programming language provided by National Instruments that uses icons instead of text lines in order to create applications. Unlike text-based programming languages, where instructions determine the program execution order, LabVIEW uses dataflow programming. In this case, the data flow through the nodes on the block diagram determines the execution order of VIs and functions.

2. Description and Modeling of Microgrid Components

The analyzed microgrid includes photoelectric and wind generation sources, an electrical energy storage system based on electrochemical operation, provided with lead-acid electrical accumulators as well as energy users.

2.1. PV system description and modeling

The mathematical models developed for photovoltaic panel systems are used to simulate (numerically) and test different microgrid configurations including renewable energy sources, users and storage elements.

These models are also used for the testing and validation of management algorithms in order to maintain acceptable voltage limits in the microgrid points as well as for the power flow control regarding the optimization of both the generated energy and the operation cost [16].

The simplified mathematical model for the photovoltaic panel is based on the single diode model of the photoelectric cell, shown in Fig. 1, where:

- G - Solar irradiance [W/m^2].
- T - Cell temperature [K].
- I_{ph} - Electric generated current [A] according to the values of irradiance and temperature (the theoretical cell current).
- D - Diode which models the p-n junction for the solar cell.
- R_{sh} and R_S - Shunt and series resistors which model the equipment power losses.

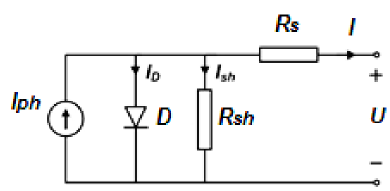

Fig.1. The equivalent circuit of the solar cell with a single diode

The single diode model of the solar cell is the most used model representing the characteristics of a p-n junction.

The electric current generated by the solar cell, I, can be written as [17]:

$$I = I_{ph} - I_d - \frac{U + R_S \cdot I}{R_{sh}} \tag{1}$$

Where I_d represents electric current which considers the cell's recombination processes and I_{sh} represents electric current through R_{sh} resistor.

The electric current I_d is determined based on the saturation current I_0 which practically corresponds to the inverted electric current [17]:

$$I_d = I_0 \cdot \left(e^{\frac{U_d}{U_T}} - 1 \right) \tag{2}$$

The value of the electric current I_0 depends on the temperature value. For a 300 K temperature and high quality cells, $I_0 = 10^8$ A/m^2. When considering the equation (2), the voltage U_d represents the cell's terminal voltage while U_T is the thermal voltage of the semiconductor (for a 300K voltage, resulting in $U_T = 0.026$ V) [17]:

$$U_T = \frac{n \cdot K \cdot T}{q} \tag{3}$$

where n is a constant (practically equal to the unity), q – electron charge ($1.6 \cdot 10^{-19}$ C); K – Boltzmann's constant ($1.38 \cdot 10^{-23}$ J/K), T – absolute temperature (K).

For the equivalent diagram shown within Fig. 1, the values for the electric values I and U can be determined from:

$$\begin{gathered} I = I_{pv} - I_0 \cdot \left(e^{\frac{U + I \cdot R_s}{U_T}} - 1 \right); \\ U = U_T \cdot ln\left(\frac{I_{ph} - I + I_0}{I_0} \right) - I \cdot R_s \,. \end{gathered} \tag{4}$$

The output power P resulting from the diagram is:

$$P = U \cdot I = U_T \cdot I \cdot ln\left(\frac{I_{ph} - I + I_0}{I_0} \right) - I^2 \cdot R_s \tag{5}$$

On the basis of equations (4) and (5), the electric current – voltage and power – voltage electrical characteristics are plotted (for one single photoelectric cell). The photoelectric cells' characteristics are indicated for *standard test conditions* (STC).

The model which allows the determination of the external characteristic *I(V)* for a photovoltaic panel has been implemented by LabVIEW environment. Fig. 2 shows the diagram developed for the KC200GT photovoltaic panel. The diagram uses the electrical parameters from the photovoltaic panel's technical specification supplied by the producer as well as the usual parameters from the scientific literature [17].

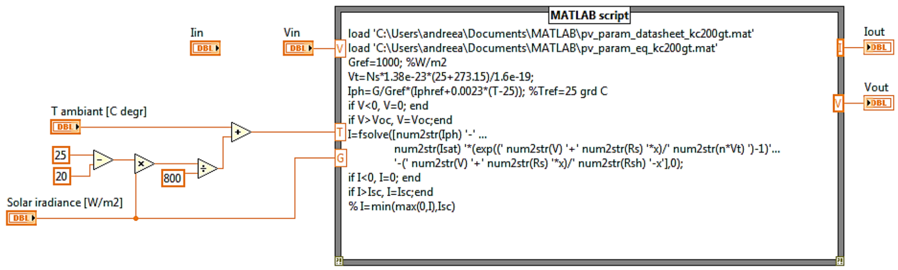

Fig. 2. The diagram developed for the KC200GT photovoltaic panel implemented in LabVIEW

The electric current - voltage characteristic of the photovoltaic panel based on the single diode model of the solar cell is shown within Fig. 3.

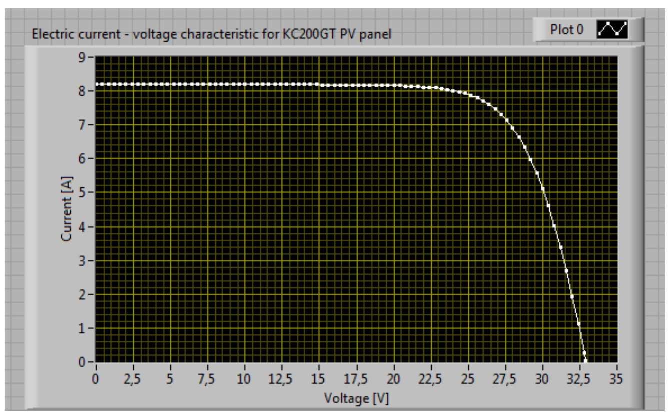

Fig. 3. The electric current - voltage characteristic of the photovoltaic panel based on the single diode model of the solar cell

After analyzing Fig. 3, it results that the open circuit voltage is 33V. It is observed that the value of the open circuit voltage for the KC200GT photovoltaic panel for standard test conditions (25 °C, AM 1.5, 1000 W/m²) is equal to 33 V (for a number of 54 cells), according to the technical specification supplied by Kyocera company (32.9 V) and exhibits a small variation with the electric current value.

2.2. Wind turbine system description and modeling

The wind turbines are used mainly for two purposes: in order to supply the electric power to isolated facilities (without any connection to the public grid) or in order for them to be included within a wind power plant, with energy injection into the electric grid. Given the irregular nature of the wind, in the case of isolated structures power supplying, the wind groups are used together with other energy sources (e.g. photovoltaic panels), as well as storage batteries.

The theoretical power transferred into the wind turbine, P_{abs} [W], is expressed by the equation (6):

$$P_{abs} = \frac{1}{2}\rho A C_p v_1^3 \tag{6}$$

where:

- C_p represents the power coefficient;
- ρ - Air density, in kg/m^3;
- A - Area of the surface described by the turbine rotor, perpendicular onto the wind direction, in m^2;
- v_1 - Wind speed at the turbine entrance, in m/s.

The power coefficient from the equation (6) can be determined as:

$$C_p = \frac{2P_{abs}}{\rho A v_1^3} \tag{7}$$

Fig. 4 shows the diagram developed for computing the power generated by a wind turbine, according to equation (6), where the air density was considered ρ=1.225 kg/m^3. The application input parameters are the nominal power of the wind turbine and the site's wind speed. The output parameters are the same as for the photovoltaic panels, namely the electric current and the voltage of the wind turbine.

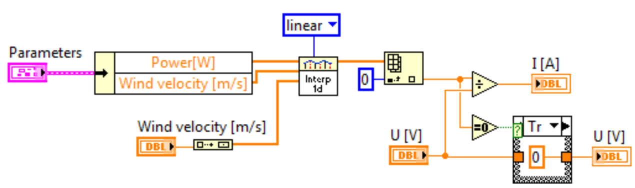

Fig. 4. The diagram of the wind turbine developed implemented in LabVIEW

2.3. Battery storage system description and modeling

The storage batteries models aim to emulate their electrical behavior, and are used to predict their parameters under varying conditions of charging or discharging. The models are also used for the design of the systems supplied by the batteries making it possible to analyze the charge/discharge impact independently of supplied system.

The Shepherd model [18] is the most used model in the simulations developed for both batteries and hybrid electric vehicles. This model describes the electrochemical processes by considering the voltage and electric current. The

Shepherd model is used by taking into account the Peukert law for determining the voltage at the battery terminals and the state of charge and consists of:

$$E_b = E_0 - R_i I - K_i \left(\frac{1}{1-f} \right) I \tag{8}$$

Where:

- E_b represents the voltage at the battery terminals [V];
- E_0 - Open circuit voltage at the battery terminals when the battery is completely charged [V];
- R_i - Battery's internal resistance [Ω].
- K_i - Battery's polarization resistance [Ω].
- Q - Battery's capacity [Ah].
- I - Instantaneous value of the electric current [A].
- f - Fraction extracted from the battery (the capacity extracted from the battery rated to the fully charged battery's capacity Q_0).

$$f = \int_0^t \frac{I \cdot dt}{Q_0} \tag{9}$$

If the battery is fully charged, then f converges to 0, with a high value of the polarization resistance. If the battery is discharged, then the value of f rises and consequently, the value of the polarization resistance drops.

The model which allows computing the voltage at the battery terminals for a storage battery has been implemented with LabVIEW software. This model allows both the terminal voltage and the electric current output and is represented within Fig. 5.

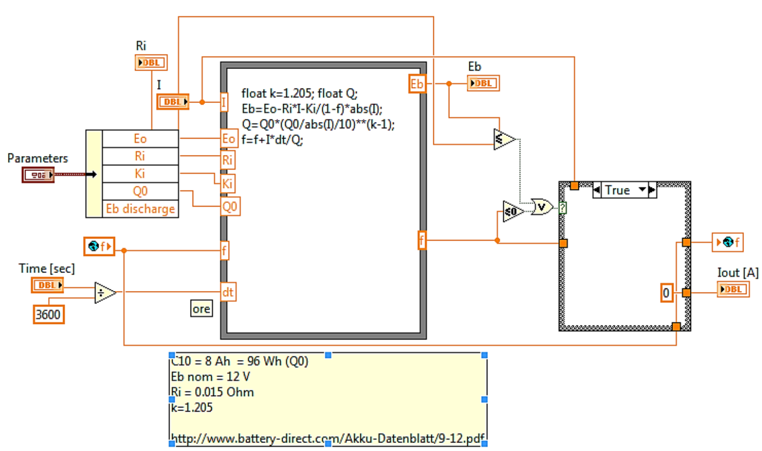

Fig. 5. The diagram developed for the storage battery modeling implemented in LabVIEW

3. LabVIEW design and simulation of small scale microgrid

The generated application addresses the LabVIEW design and simulation of the operation of a microgrid. The microgrid was implemented by integrating the models developed for the renewable energy sources, for the storage elements as well as for the end-users with load curves and characteristics derived from the client database. Previously, the location was provided with the monitoring of the meteorological parameters and the electric power forecasting, respectively. This was achieved following the analysis of several initial locations and concluding that Dobrogea area is the optimum location for setting-up the meteorological parameters monitoring system, specifically for the microgrid to be referred at.

Fig. 6 shows a diagram section developed for the LabVIEW design and simulation of a small scale microgrid.

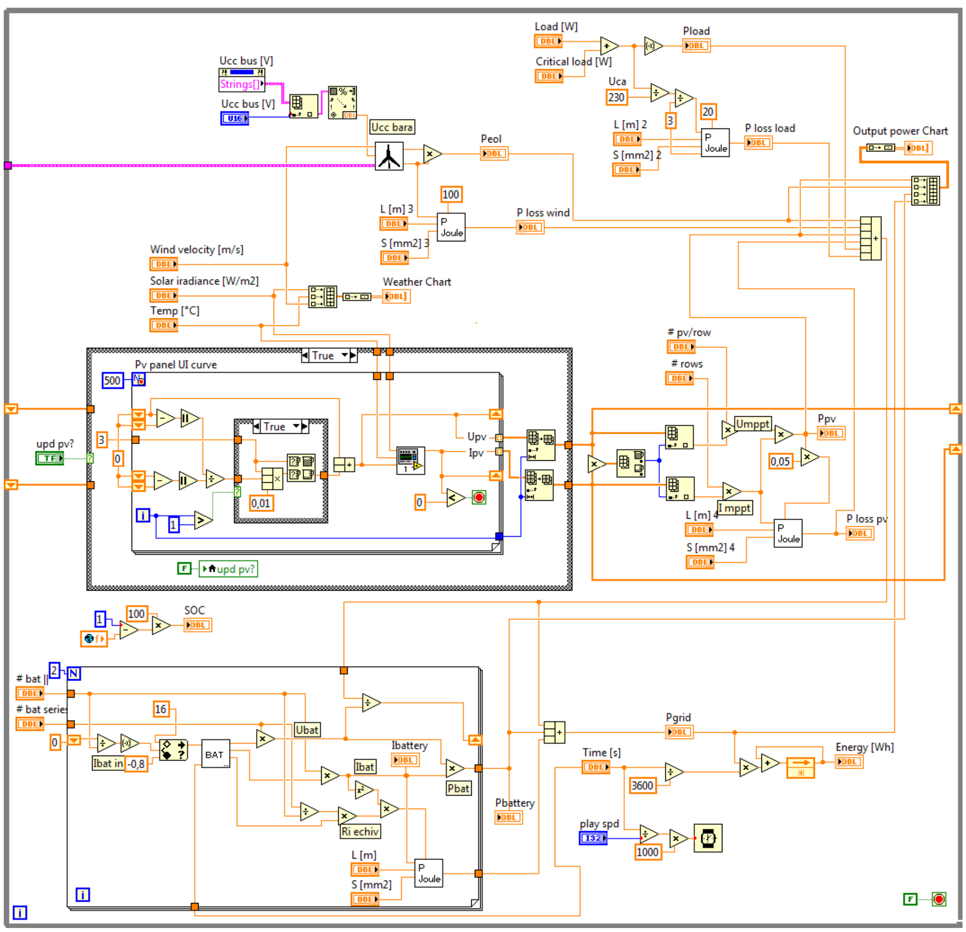

Fig. 6. The LabVIEW design and simulation of a small scale microgrid

The diagram shown within Fig. 6 is accessed through the graphical interface shown in Fig. 7. The LabVIEW design and simulation diagram and the graphical interface of the program, respectively, consist of four sections:

1. The section designed for establishing the meteorological parameters related to the geographic region where the microgrid is located.
2. The section designed for identifying and establishing both the microgrid components as well as the load which needs to be ensured.
3. The section designed for displaying the values of the generated power produced by the renewable energy sources, the power losses, the power generated or absorbed by the storage battery and the power injected or extracted from the public grid.
4. The section designed for the graphical time representation for the meteorological parameters and the generated power, respectively.

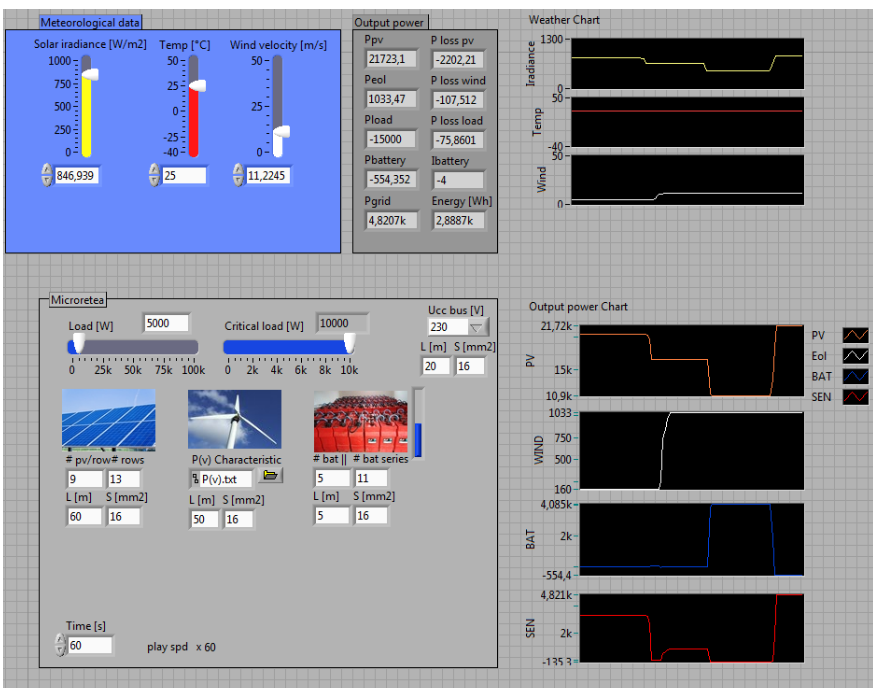

Fig. 7. The graphical interface of the LabVIEW application for the design and simulation of a small scale microgrid

The section designed for establishing the meteorological parameters related to the geographic region where the microgrid is located enables the insertion of the solar irradiation, the ambient temperature and the site wind speed.

The second section allows the establishment of the number of installed photovoltaic panels in series or parallel, of the P(v) characteristic (dependency between the wind turbine power and wind speed) and of the energy storage capacity related to renewable energy sources production.

The operation principle of the developed microgrid envisages the users' power supply from the available renewable energy sources. The batteries are designed to accumulate the surplus energy produced by the microgrid and to complete the energy necessary, when the available resources are unable to provide it. The microgrid is able to operate interconnected with the local distribution system operator. In this way, the excess electricity produced by the microgrid (resulted after power supplying the users and batteries charging) is injected into the public grid.

The developed microgrid model also considers the power losses, namely:

- Technical [cable] losses - losses which are load dependent (by Joule effect), where:

$$P = R \cdot I^2 = \frac{\rho \cdot l}{S} \cdot I^2 \qquad (10)$$

- Losses generated by the power electronic devices.

The diagram used for the determination of the power losses and included in the LabVIEW diagram shown within Fig. 6, is provided by Fig. 8.

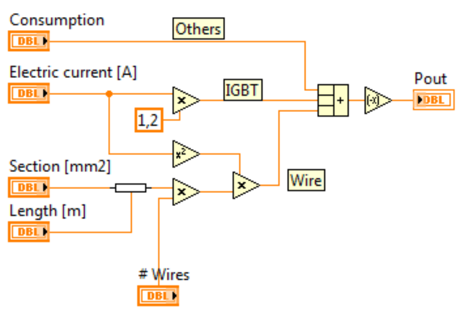

Fig. 8. The LabVIEW diagram developed for the power losses' design and simulation within a small scale microgrid

The parameters considered for the microgrid simulation are characteristic to the beneficiary. The values have been estimated by considering the real sizes of the available building.

Fig. 7 shows the values for the photovoltaic panels and wind turbine powers as well as the values for the power which is extracted from both the public grid and the storage batteries for bad weather conditions, unfavorable to renewable energy sources availability.

It is to be noticed that the graphical interface of the LabVIEW application for the design and simulation of the considered microgrid provides particular results customized for the installed power of the generation sources as well as for the load size. Also, Fig. 7 provides the microgrid simulations obtained for different variations of the considered input parameters demonstrating that the power consumption can be assured by the photovoltaic sources (P_{pv} = 21.73 kW) and the wind energy system (P_{eol} = 1.03 kW) while the excedent production can be injected into the National Power System .

4. Conclusions

The paper has presented the LabVIEW design and simulation of a small scale microgrid. The microgrid modeling was achieved for the service of a real user, location where results have been made available from monitoring of the meteorological parameters and electric power forecasting.

In the first section, description and mathematical modeling of the microgrid components (photovoltaic panels, wind turbines and storage batteries) are introduced. The microgrid modeling was achieved by integrating the developed applications related to renewable energy sources, storage elements and energy users into the LabVIEW environment.

The final application is provided with a graphical interface for the design and simulation of a small scale microgrid which allows the identification of initial conditions (meteorological parameters, components) as well as of the set points of microgrid operation.

R E F E R E N C E S

[1]. Summary Report, DOE Microgrid Workshop, Chicago, Illinois, 2012.

[2]. B. Qiang Fu, A. Hamidi, A. Nasiri, V. Bhavaraju, S. (Bob) Krstic, and P. Theisen, "The Role of Energy Storage in a Microgrid Concept", IEEE Electrification Magazine Digital Object Identifier 10.1109/MELE.2013.2294736, February 2014.

[3]. *R. Lasseter, A. Akhil, C. Marnay, J. Stephens, J. Dagle, R. Guttromson, A. S. Meliopoulous, R. Yinger, and J. Eto*, "White paper on integration of distributed energy resources: The CERTS microgrid concept", LBNL-50829, Office of Power Technologies, the US Department of Energy, Berkeley, CA, Tech. Rep. DE-AC03-76SFW098, Apr. 2002.

[4]. *R. Lasseter*, "Microgrids," in Proc. IEEE Power Engineering Society Winter Meeting, 2002, vol. 1, 2002, pp. 305 – 308.

[5]. *R. Magureanu, M. Albu, M. Priboianu, V. Bostan*, 2006, "Solutions for Small Hydropower Plants Integration into Distribution Networks", Proc. of WREC Congress 2006, Florence, Italy, ISBN 008 44671 X.

[6]. *R. Magureanu, Mihaela Albu, A. M. Dumitrescu, M. Priboianu,* "A practical solution for grid connected dispersed generation from renewable sources: DC connection", Proc. of SPEEDAM 2006 – IEEE Conference, Taormina, June 2006, ISBN: 1-4244-0193-3.

[7]. *N. Hatziargyriou, H. Asona, R. Iravani, and C. Marnay*, "Microgrids", IEEE Power Energy Mag., vol. 5, no. 4, Jul./Aug. 2007, pp. 78–94.

[8]. *E. Barklund, N. Pogaku, M. Prodanovic, C. Hernandez-Aramburo, and T. C.* Green, "Energy management in autonomous microgrid using stability-constrained droop control of inverters", IEEE Trans. Power Electron., vol. 23, no. 5, August 2008, pp. 2346–2352.

[9]. H. *Morais, P. Kadar, M. Cardoso, Z. A. Vale and H. Khodr*, "VPP operating in the isolated grid," in Proc. IEEE Power and Energy Society General Meeting, Jul. 2008, pp. 1–6.

[10]. E. *Alvarez, A. Lopez, J. Gomez-Aleixandre, and N. de Abajo*, "Online minimization of running costs, greenhouse gas emissions and the impact of distributed generation using microgrids on the electrical system", in Proc. IEEE Conference on Sustainable Alternative Energy (SAE), Sept. 2009,pp. 1–10.
[11]. *F. Katiraei*, "Dynamic analysis and control of distributed energy resource in a microgrid", Ph.D. Dissertation, Univ. Toronto, Dept. Electr. Comput. Eng., Fall 2005.
[12]. *F. Katiraei, M. R. Iravani, and P. W. Lehn*, "Micro-grid autonomous operation during and subsequent to islanding process," IEEE Trans. Power Del., vol. 20, no. 1, Jan. 2005, pp. 248–257.
[13]. F. *Katiraei and M. R. Iravani*, "Power management strategies for a microgrid with multiple distributed generation units", IEEE Trans. Power Syst., vol. 21, no. 4, Nov. 2006, pp. 1821–1831.
[14]. H. *Nikkhajoei and R. H. Lasseter*, "Distributed generation interface to the CERTS microgrid", IEEE Trans. Power Del., vol. 24, no. 3, Jul. 2009, pp.1598–1608.
[15]. *W.D. Zheng and J.-D. Cai*, "A multi-agent system for distributed energy resources control in microgrid," in Proc. IEEE 5th International Conference on Critical Infrastructure (CRIS), Sept. 2010, pp. 1–5.
[16]. *** http://www.aut.upt.ro/microren/raport.pdf. Proiect finanţat de UEFISCDI: Parteneriate în Domenii Prioritare PNII 2011 - Sisteme hibride de conversie a energiei regenerabile de mică putere integrate într-o microreţea, ACRONIM: MICROREN, Coordonator: Universitatea „Politehnica" din Timişoara.
[17]. *Chouder A., Silvestre S., Taghezouit B., Karatepe E.*, "Monitoring, modelling and simulation of PV systems using LabVIEW", Solar Energy, 2012.
[18]. *Peukert W.*, Über die Abhängigkeit der Kapazität von der Entladestromstärke bei Bleiakkumulatoren, Elektrotechnische Zeitschrift 20, 1897.