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THE PERFORMANCE IMPROVEMENT OF A HYBRID SUPPLY SYSTEM

BY

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Abstract. The paper presents the performance improvement of a PV-battery system interfaced with the local distribution network. The hybrid system is used to supply DC and/or AC consumers. The first supply source is represented by the electric energy distribution network. In the cases when this source fails, the AC local consumers are supplied by the PV modules or by the battery through a single phase inverter. In this paper the behaviour of the AC local consumer (a resistive-inductive consumer was considered) when two inverter types are used is analysed: one with modified sine wave and other with pure sine wave. Also, we performed a harmonic analysis of the current and voltage absorbed by AC consumers in the analyzed cases.

Key words: PV hybrid supply systems; efficiency; pure sine wave; modified sine wave.

1. Introduction

In the last years hybrid supply systems have been developed, which combine renewable energy sources (wind, geothermal, biomass, solar, fuel cell, etc.) with conventional ones (gas, oil, coal) (Stănescu *et al.*, 2015). The literature presents multiple architectures for these hybrid systems which are used

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to supply different types of consumers. A modality is to combine the solar and wind energy with fuel cell (Paska *et al.*, 2005; Zahedi, 2007). Other modalities are to combine the PV modules (solar energy) with grid/microgrids (Du *et al.*, 2014; Selvaraj *et al.*, 2009; Yang *et al.*, 2010) and PV modules with the distribution network (Coddington *et al*, 2011; Sugihara, *et al.*, 2013; Yazdani *et al*, 2009). For isolated consumers it is necessary to have a versatile hybrid supply system. The goal of the paper is to present such a supply system (PV-battery-local distribution network) and the modality to supply the AC consumers. The efficiency of the system is increased when the AC consumers are supplied by a pure sine wave inverter in the case when the first supply source (distribution network) fails.

The paper is organized as follows. Section **2** presents the main aspects of the entire hybrid system's realization. In the section **3**, the experimental results obtained during tests, when two types of inverter (with modified sine wave and pure sine wave) are used, are given. Finally, the conclusions of this paper are presented in section 4 (Stănescu *et al*., 2015).

2. The Hybrid Supply System Realization

Fig. 1 depicts the block scheme of the entire hybrid supply system. In the designing stage the followings were taken into account: the local distribution network is the first supply source of the AC and DC consumers; the second supply source is represented by the PV modules (in the sunny days) or the storage battery (in days with low light intensity or during the night time). These are used in cases when a failure occurs in the local distribution network.

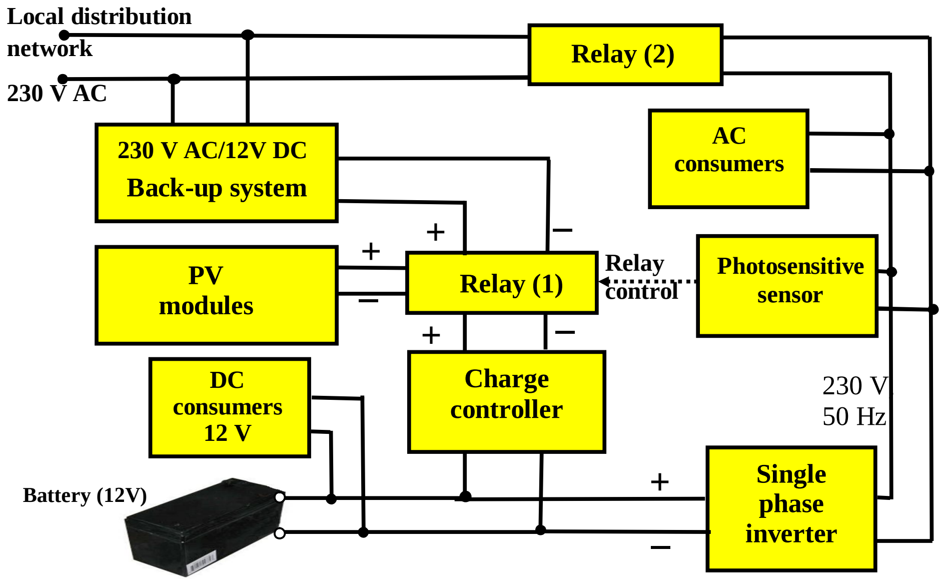

Fig. 1 – The block scheme of the entire hybrid supply system.

The system operation was described in detail in a previous work (Stănescu *et al.*, accepted). The inverters used to supply AC consumers in the failure cases have the following rated data: DC input voltage 12 V – output voltage/power 230V/75 W (modified sine wave), DC input voltage 10-16 V – output voltage/power 230V/300-1,500 W (pure sine wave). The first one is a low price single phase inverter used to supply low power consumers which are not affected by a high THD (total harmonic distortion). The other type is more complex and it is used to supply special consumers like motors, fans, TV sets, computers (PSWI_MSWI, 2015). The output voltage has a low THD and in this way the audible and the electrical noise are reduced at the consumers (fluorescent lamps, TV sets) and the damage of the PCs (personal computers) and of other similar equipment is prevented (PSWI_MSWI, 2015; Stănescu *et al.*, 2015).

Fig. 2 presents an image of the analyzed hybrid supply system under experimental tests in the laboratory of the Faculty of Electrical Engineering, Craiova.

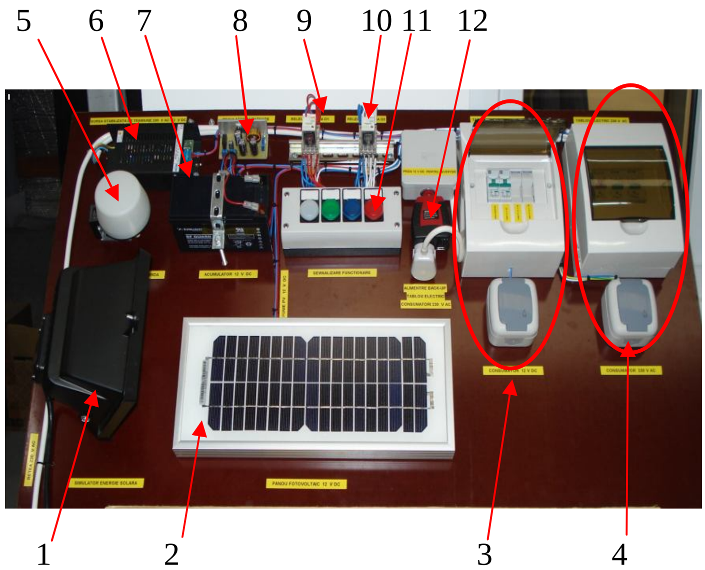

Fig. 2 – The hybrid supply system used in experimental tests.

In this Fig. 1 represents a lamp used to simulate a high light intensity; 2 represents the PV module; 3 represents the 12 V DC output and 4 represents the 230 V AC output for local consumers; 5 is the photosensitive sensor (PS) used to control the relay (1); 6 represents the back-up system interconnected between the local distribution network, the PV module and the battery; 7 represents the 12 V battery, 8 is the charge controller, 9 and 10 represent the relays; 11 is a signaling block, 12 represents the single phase inverter place (with modified sine wave or with pure sine wave) (Stănescu *et al.*, 2015; Stănescu *et al.*, accepted).

A zoom of the points 6, 8 and 9 from Fig.1 is presented in Figs. 3 and 4.

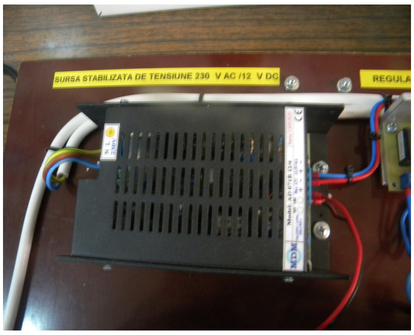

Fig. 3 – The back up system.

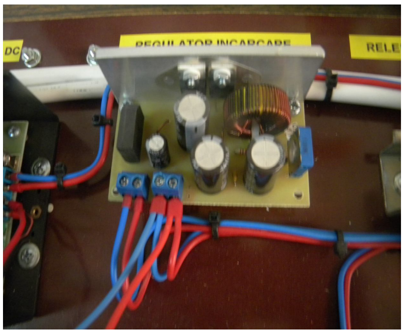

Fig. 4 – The charge regulator.

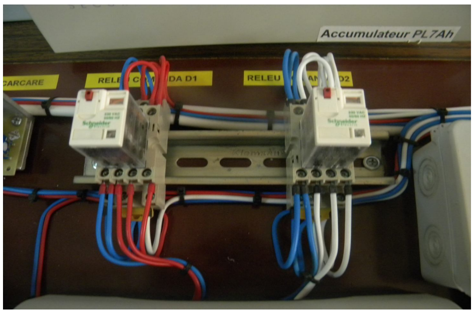

Fig. 5 – The relays used to insure the supply of the a.c. local consumer.

The two relays from Fig. 5 have a role in supplying the AC consumers from the local distribution network (relay 2 – Fig.1). In the failure cases of the distribution network, the relay 1 (Fig.1) is used to ensure the supply of the AC consumers from PV modules or from the battery. This relay is controlled by the photosensitive sensor (Stănescu *et al.*, accepted). The battery used to test the systems is a commercial battery, but it depends on the application; this one could be changed with another one, more efficient, like supercapacitor battery.

3. The Experimental Results with the Proposed Hybrid Supply System Using Two Inverter Types on the A.C. Side

We realized experimental tests considering the AC consumer (a resistive-inductive load) supplied by two types of inverters: a modified sine wave inverter (Cheema *et al.*, 2015) (Fig. 6) and a pure sine wave inverter (Fig. 7) (Stănescu *et al.*, 2015). For the analyzed case we performed afterwards a harmonic decomposition based on the Fast Fourier Transform (FFT) (Nicolae *et al.*, 2010). The fundamental frequency is 50 Hz.

Fig. 6 – A commercial modified sine wave inverter.

Fig. 7 – A commercial pure sine wave inverter.

The total harmonic distortion for the current (ITHD) and respectively for the voltage (VTHD) was computed based on the following equation:

$$THD=\frac{\sqrt{\sum_{k=2}^{n} X_k^2}}{X_1} \tag{1}$$

where: X_k represents the magnitude of the current/voltage harmonics and X_1 represents the magnitude of the fundamental current/voltage.

Fig. 8 depicts the voltage and current waveforms obtained during experimental tests in the case when the resistive-inductive consumer is supplied by the modified sine wave inverter. We used a quality analyzer to record these waveforms absorbed by the load (Stănescu *et al*., 2015).

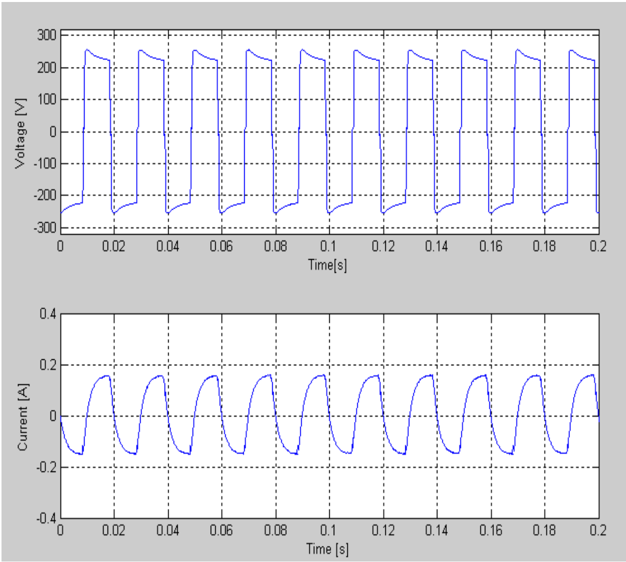

Fig. 8 – The voltage and current waveforms recorded in the case with resistive-inductive load supplied by the modified sine wave inverter.

The harmonic decomposition of the recorded waveforms is depicted in Fig. 9.

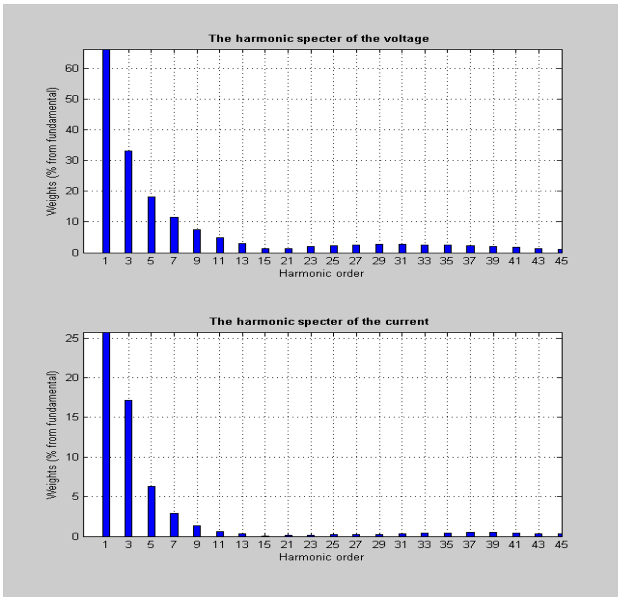

Fig. 9 – The harmonic spectra of the voltage and of the current absorbed by the resistive-inductive load.

In Fig. 9 the voltage and the current harmonics are represented with their weights as percent of the fundamental. The magnitude of the fundamental voltage was 211 V and the magnitude of the fundamental current was 0.117 A respectively.

The recorded current waveform presents a significant distortion. In Tables 1 and 2 the values of these harmonics and the total harmonic distortions of the current and of the voltage are presented. If it is necessary to supply more consumers with a low THD, a different type of inverter must be used, like the pure sine wave inverter (Stănescu *et al.*, 2015).

Table 1
The Magnitude of the Current Harmonics for a Resistive - Inductive Consumer

Harmonic order	3	5	7	9	11	13	15	21	23	25
Magnitude [mA]	20.2	7.38	3.42	1.5	0.72	0.39	0.07	0.1	0.2	0.3
Harmonic order	27	29	31	33	35	37	39	41	43	45
Magnitude [mA]	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.4	0.3	0.3
ITHD, [%]	18.39%									

Table 2
The Magnitude of the Voltage Harmonics for a Resistive - Inductive Consumer

Harmonic order	3	5	7	9	11	13	15	21	23	25
Magnitude [V]	70.2	38.6	24.2	15.8	10.2	6.1	2.9	2.9	4	4.8
Harmonic order	27	29	31	33	35	37	39	41	43	45
Magnitude [V]	5.3	5.6	5.5	5.4	5.1	4.7	4.1	3.5	2.9	2
VTHD, [%]	38.35%									

In Fig. 10 the voltage and the current waveforms obtained during experimental tests in the case when the resistive-inductive consumer is supplied by the pure sine wave inverter are presented. In this case the waveforms are almost sinusoidal. Indeed the FFT analysis reveals that THD for the recorded waveforms (current and voltage) is less than 3%, proving a main advantage for this second inverter type as it is presented in Table 3.

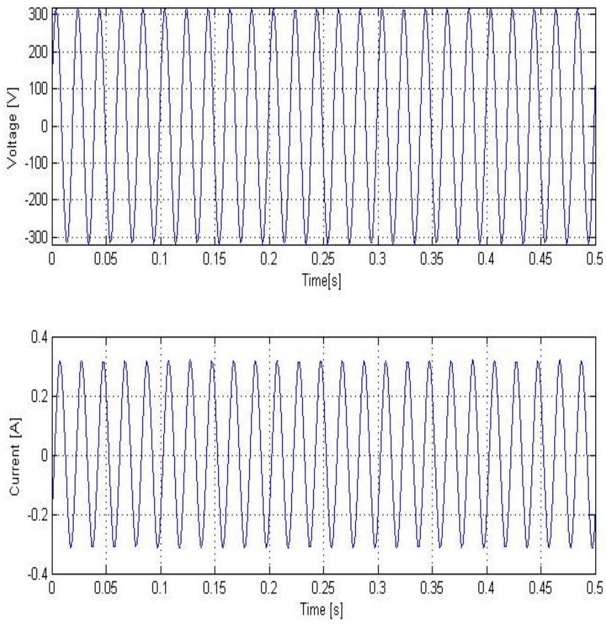

Fig. 10 – The voltage and current waveforms recorded in the case with resistive-inductive consumer supplied by the pure sine wave inverter.

Table 3
The Analysis of the Recorded Waveforms

	Voltage, [V]	Current, [A]
Magnitude (RMS) of the fundamental	221.9474	0.21903
THD, [%]	1.2063	2.6

4. Conclusions

In this paper a PV-battery interfaced with the local distribution network is analyzed. Aspects regarding the realization of the entire hybrid system are presented. The battery is charged by the local distribution network through the back-up system.

The hybrid supply system is analyzed in the paper taking into account that the local distribution network fails. In such cases the AC consumers are supplied from battery or PV modules through a single phase inverter.

The system was tested considering for AC consumer (resistive-inductive load) two types of inverter: single phase modified and respectively pure sine wave inverters.

The experimental tests were realized in the Laboratory of Electrotechnics from the Faculty of Electrical Engineering, University of Craiova.

In the first case, when a low price inverter was used, the harmonic decompositions of the current and voltage absorbed by the resistive-inductive load proved a large THD. The computed values for the ITHD and for the VTHD are 38.35% and respectively 18.39%.

If the AC consumer imposed it, the cheaper inverter can be changed with a pure sine wave inverter, more complex and more expensive, but with THD of its output quantities below 3%.

The hybrid supply system can be improved with a positioning systems used for the PV modules. This system is necessary in the regions where the position of the sun during the day affects the efficiency of an immobile PV system. Using positioning systems, the PV modules are orientated following the sun and the efficiency of the system could be increased.

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ÎMBUNĂTĂȚIREA PERFORMANȚELOR UNUI SISTEM DE ALIMENTARE HIBRID

(Rezumat)

Este prezentat un mod de îmbunătățire a performanțelor unui sistem format din module PV şi baterii interfațat cu rețeaua de distribuție locală. Sistemul hibrid este utilizat pentru alimentarea consumatorilor de curent continuu şi/sau curent alternativ. Sursa primară de alimentare este considerată rețeaua de distribuție locală a energiei electrice. În cazul unor avarii în rețea, consumatorii locali de curent alternativ sunt alimentați prin intermediul unui invertor monofazat de la panourile fotovoltaice sau de la bateria de stocare a energiei electrice. In lucrare este analizată comportarea unui consumator local (considerat rezistiv-inductiv) în cazul utilizării a două tipuri de invertoare: cu undă modificată sinusoidal şi cu undă pur sinusoidală. De asemenea, s-a efectuat o descompunere armonică a formelor de undă pentru curentul şi tensiunea absorbite de către consumatorul de curent alternativ în cazurile analizate.