Optimize of the Long-Term Supply for a Detection, Vibration Monitoring and Recognition of the Critical Infrastructure Protection System

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Abstract – In this paper is presented a solution for long-term power supply optimization implemented in a system for detection, monitoring and recognition of ground vibrations resulting from human activity to protect critical infrastructure. These systems must use besides conventional energy sources the backup energy sources to offer over to 300 days autonomy without maintenance. This autonomy can be obtained by using renewable energy sources, such as based on solar panels proposed here. Besides the technical constraints (dimensions, complexity, lifetime etc.) and economic targets (low price solutions), the energy efficiency must be the main objective of the design for these systems. So, an advanced algorithm based on Extremum Seeking Control (ESC) is proposed to harvest the maximum power generated by the solar panels. The ESC algorithm was designed to meet the imposed performance (high search speed and accuracy, low power ripple during stationary regime etc.) and then analyzed by simulation. The experimental results validate the obtained performance in simulation and the theoretical assumptions made.

Keywords- Renewable energy, Extremum Seeking Control (ESC), Maximum Power Point Tracking (MPPT), Digital Signal Processing (DSP), critical infrastructure, Processor In the Loop (PIL)

I. INTRODUCTION

Recent events at the European and the globally level highlight the need to enhance the safety and security of civil society, very important factors to determine the quality of life. Ensuring the safety quality of life motivates us to constantly search the technical resources and the innovative solutions to eliminate the disturbing elements of the critical infrastructure, illegal border crossings, etc. [1].

The detection, monitoring and recognition of vibration for protecting of the critical infrastructure systems need, for optimal operation, of a very good solution for the power supply [2]. Currently, the cheapest and most reliable power supply systems include the photovoltaic energy sources, controlled for obtaining the maximum power.

Many techniques for maximum power point tracking (MPPT) have been developed to maximize the energy extracted from the source and transferred to the load, and most of them are well documented in the literature. These techniques can be compared in terms of: simplicity of implementation, speed of convergence, digital or analog implementation, of sensors required, cost, efficiency, etc. [3-5]. A comparative study of these algorithms, including their performance in terms of energy, is presented in Table 1.

Table 1. Major characteristics of the MPPT techniques

MPPT techniques	Dependence of PV module	Real MPPT	Analogic or digital	Periodic finding	Speed of convergence	Implementation complexity	Measured parameters
Constant Voltage (CV)	Yes	No	Analogic	No	Vary	Low	Voltage
Short circuit current (SC)	Yes	No	Both	Yes	Medium	Medium	Current
Voltage without load (OV)	Yes	No	Both	Yes	Medium	Low	Voltage
Perturb and observe (P&O)	No	Yes	Both	No	Vary	Low	Voltage, current
Conductance increment (IC)	No	Yes	Digital	No	Vary	Medium	Voltage, current, irradiation
Temperature gradient (TG)	Yes	Yes	Both	Yes	Vary	Medium	Voltage, temperature
Temperature parameter (TP)	Yes	Yes	Both	Yes	Medium	High	Voltage, temperature, Irradiation
Fuzzy logic control (FLC)	Yes	Yes	Digital	Yes	Fast	High	Vary
Extremum seeking control (ESC)	No	Yes	Both	Yes	Fast	Medium	Voltage, current
Neural network (NN)	Yes	Yes	Digital	Yes	Fast	High	Vary

The power characteristic of a PV solar cell is nonlinear and varies with the solar irradiation and temperature as well known. Normally, it is a single maximum for the power characteristic called Maximum Power Point (MPP), at which the PV system operates with maximum efficiency, generating the maximum power to supply the load. If the PV modules are integrated in large array, more local extremes can appear in case of partial shading conditions, besides the global extreme [6-7]. This problem can be analyzed with MPPT adaptive algorithms [8].

The MPP exact location is unknown, but may be located using analytical models of computing or

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through searching algorithms. Also, it is necessary to use MPPT techniques in order to maintain the PV system close to the optimum operating point (MPP). Perturb and observe techniques (P & O), incrementing conductance (IC) or variants thereof are the most used of them [9, 10].

The control algorithm should be able to find continuous the real MPP in real time and without periodical tuning. For these situations, the suitable algorithms are ESC, P&O, respectively IC.

Quantitative scientific research of evolution on MPP control algorithms, demonstrates intense concern to the researchers, the results were publicized in articles published in scientific journals, monographs, courses or scientific communications presented at international scientific meetings. Follows, are present the results of a statistical study in the scientific concern of MPP algorithms in general and especially for ESC algorithm that includes following directions/ variables/ indicators of statistical analysis:

- Scientific interest on the MPP control algorithms;

- Scientific interest on the ESC control algorithms;

Statistical data were collected from two most representative internationally databases: ISI Web of Science and SCOPUS.

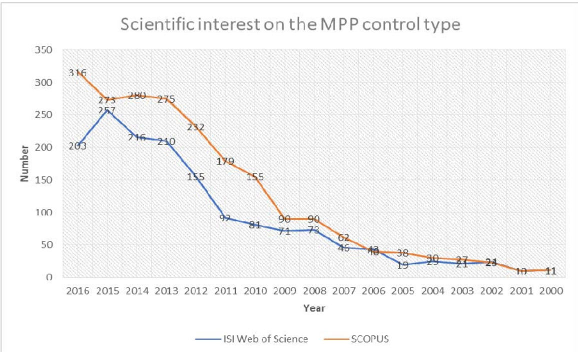

Figure 1. Scientific interest on the MPP control

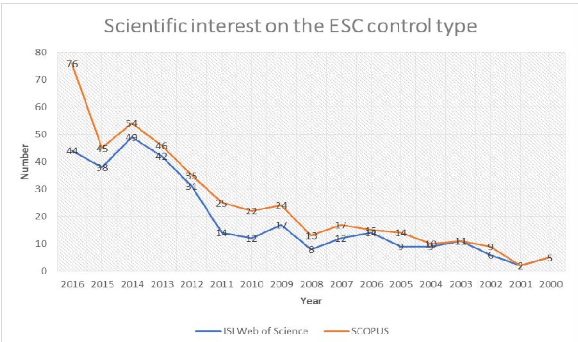

Figure 2. Scientific interest on the ESC control

From Figures 1, 2 show the growing interest on MPP control algorithms. Over the past 10 years, the number of scientific articles in the control algorithms MPP field has increased more than 23 times.

Analyzing the values from Figure 2 can be seen that, considering an average number of scientific publications that address ES control type represents approximately 26% of the total number of publications that refer to MPP control type.

The section 2 of this paper presents the ESC algorithm proposed herein for analysis and practical implementation. Also, the simulation results can be found in this section. Section 3 presents the energy supply system designed and the experimental results.

II. ESC ALGORITHM ANALIZED AN IMPLEMENTED

The algorithm chosen to be studied, analyzed, implemented and validated is an algorithm ESC type. The scheme of proposed ESC algorithm (figure 3) is a technique based on gradient, which typically uses a low amplitude sinusoidal perturbation signal.

The input signal (*P_in*) is applied to two low pass filters (LPF1) and (LPF2), which passes the carrier and a limited number of harmonics thereof. The performance of the ESC algorithm is set by tuning parameters K1 and K2 [11, 12]. To the energy system is applied a searching disturbance (dither generated by GS block), which here is a sinusoidal signal with frequency ωp. The output of the MUL1 block is integrated in the INT block and amplified by the K3 gain. To limit the MPPT algorithm convergence speed (in order to protect the power supply and DC-DC converter interface) are added to the saturation blocks, LIM1 and LIM2. At the output is obtained a signal with minimal disturbance set by K4 gain.

The reference signal is brought to an appropriate level of amplitude (specific control circuit DC-DC converter) through (K5) amplifier after is generated the PWM signal for the block PWM DC-DC converter. The output signal must ensure optimal tracking of Ref_out nonlinear feature signal. Adaptive type optimizing the level of signal search is performed by the (MUL2) block with the fundamental input signal P_in which is proportional to the nonlinear characteristic.

If both cases where the ESC control parameters, closed-loop gain value (K3) and amplitude of disturbance the parameters are established by PV source. High search speed and accuracy for MPP tracking can be ensure by adjusting these parameters. Because the amplitude of perturbation control both indicators of performance (search speed and MPP accuracy) then it had to be a compromise between these performances indicators in all ESC systems, except the ESC system proposed in [13]. It is noteworthy that the adaptive gain is proportional to the magnitude of PV power, which ensures the decreasing of dither's amplitude with approaching to the MPP point.

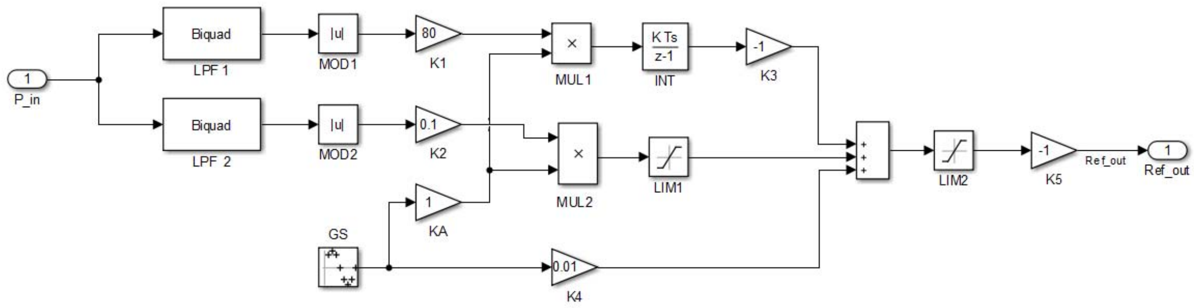

Figure 3. Matlab Simulink diagram of the Extremum Seeking Control used

Thus, the perturbation amplitude (which can be initially set by KA gain) decreases to almost zero after MPP point is caught. Therefore, the ripple of PV power becomes insignificant during the stationary regimes.

The gain value (K2) in closed-loop could be set higher to get a higher search speed during the transient phase. Typically, the gain is set proportionally to the frequency perturbation signal, up to a safety value that is linked to the power profile slopes in case of the partial shade.

Simulation results show that it is possible to achieve the following performance:

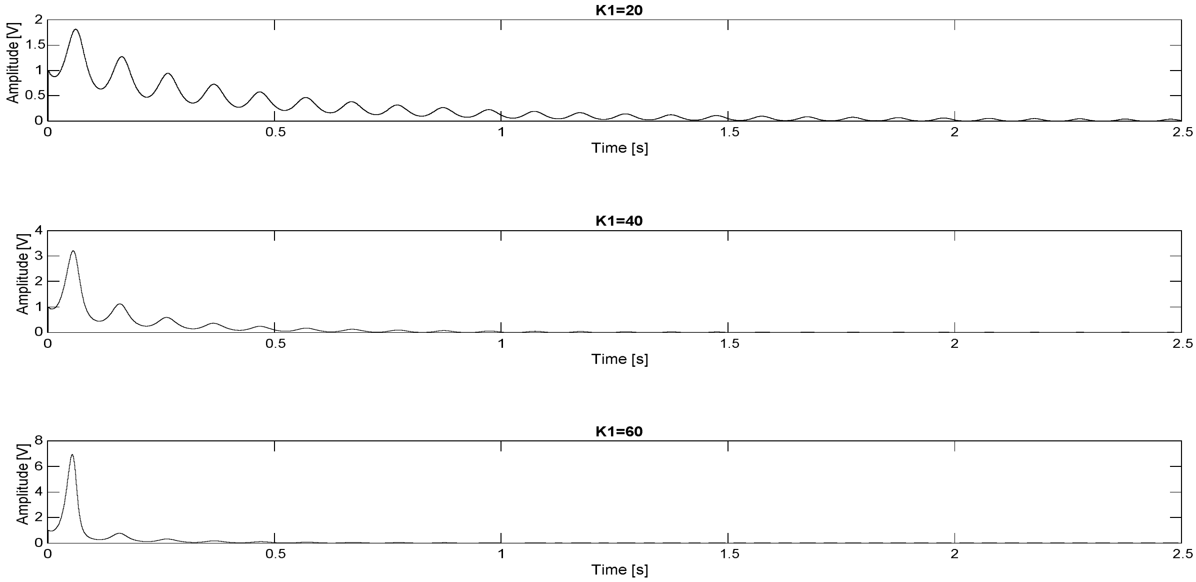

Figure 4. Influence of tuning parameter K1 to searching speed of ESC algorithm

Search speed increases proportionally with K1, K2 concerned, but also increases the initial error search amplitude.

In the figure 4 is given an example of the three individual values of K1 = (20, 40, 60) and a perturbation signal amplitude that is initially set by K2 = 0.1;

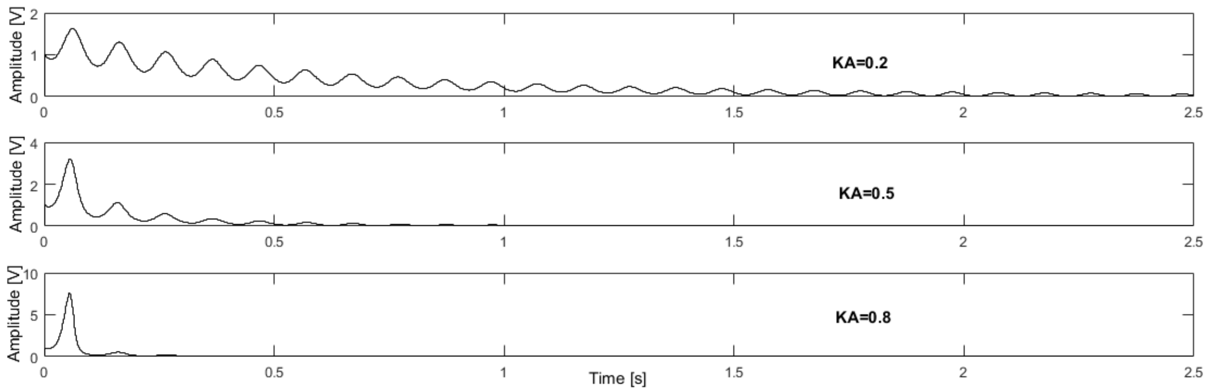

Figure 5. Influence of tuning parameter KA to searching speed of ESC

In figure 5 is given an example for three individual values of KA = (0.1, 0.4, 0.7), considering K1 = 40;

An input step signal, according to three levels of solar irradiation (Figure 6, plot 1) is used in testing performance tracking of MPP for ES control. This levels are 0 – to 300 w/m^2, 1 – to 500 w/m^2, 2 – to 700 w/m^2. MPP tracking is shown in Figure 6, Plot 2.

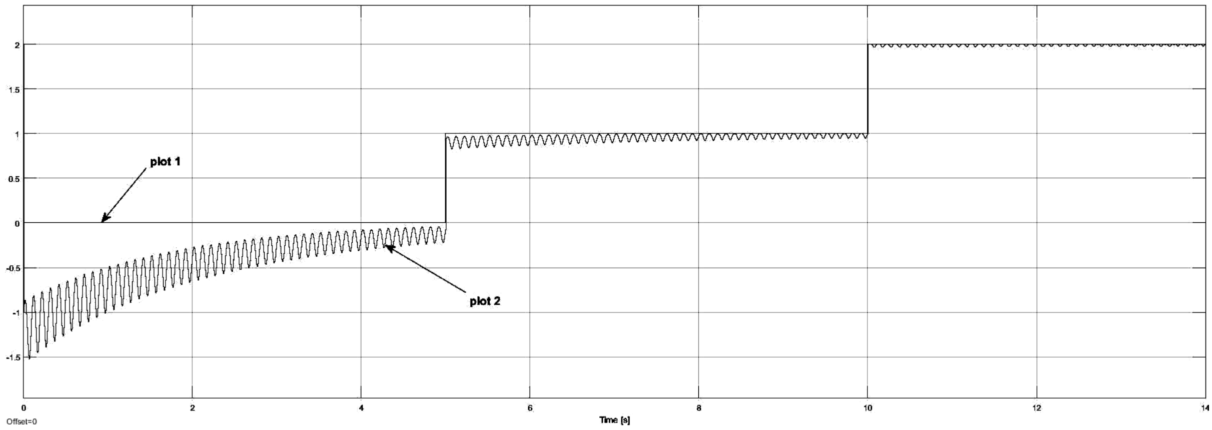

Figure 6. The system response to steps in input signal

It can be seen that the searching error waveform adapts to every jump of the input signal. Disturbing signal amplitude shrinks with reaching the search point remains the default value of K4.

III. EXPERIMENTAL RESULTS

In the SmartVibes project (System for detection, monitoring and recognition of ground vibrations resulting to protect critical infrastructure) is used an off-greed power supply using PV. The PV is a system that converts sunlight into electricity. It is safe, reliable, require minimal maintenance and provide energy where it is needed, without issuing any kind of pollutants. Also, the system does not require high operational costs and is easy to install.

In the SmartVibes project for power supply are used the components shown in figure 7.

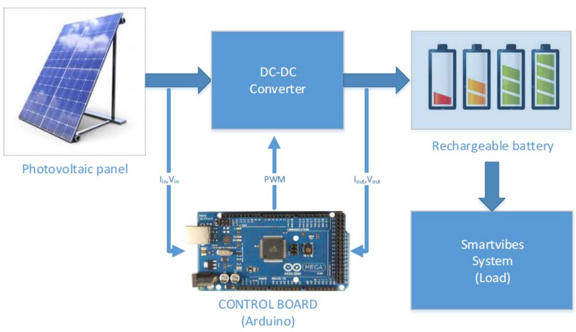

Figure 7. The used photovoltaic power system

Operating conditions imposed by the design are:

• Continuous and efficient operation using intelligent control techniques [14];
• Autonomy without maintenance of over 350 days
• Nominal power supplied of 100W.

The system was designed based on ECO-PV photovoltaic panel manufactured by Solar Enjoy with the following technical data:

- Power (Wp): 130W
- Maximum Voltage (Vmp): 18 V
- Short circuit current (Isc): 7,77 A
- Peak current (Imp): 7,22 A
- Open circuit voltage (Voc): 22,1 V
- Monocrystalline.

It is chosen a VRLA battery, 12V, dedicated to solar and wind energy storage, communications systems, UPS, electric lifting platforms, etc., during backup is approximately 15 hours

To increase the backup time, especially in winter operation, it was acquired in the same project, a solar controller that allows the implementation of own algorithms of search MPP

The experimental module for extracting the measurements and the experimental results it is shown in Figure 8. The PV was replaced by a controllable power source (with voltage and current control). The controller is built with a dc-dc buck converter. To implement ESC algorithm was used a Processor-In-the Loop (PIL) technique. Acquisition and control board used is based on a system based on ATMEGA 128. The load of the system is a battery in parallel with a consumer resistive.

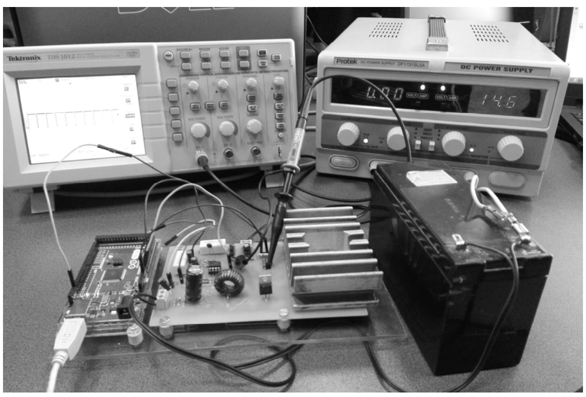

Figure 8. The laboratory experimental system

The experimental module acquires the information about input and output power of DC-DC converter. The acquired signals are processed in Matlab Simulink using an ES control algorithm.

The measurements were effectuated for the various operating conditions. In figure 9-11 are show the charts derived from measurements taking into account the values of the control parameters for the ESC diagram (figure 3). The control parameters used are present in Table 2.

Table 2. The control parameters used in measurements made

No.	K1	K2	KA
1	20	0.1	0.2
2	40	0.1	0.2
3	20	0.1	0.8

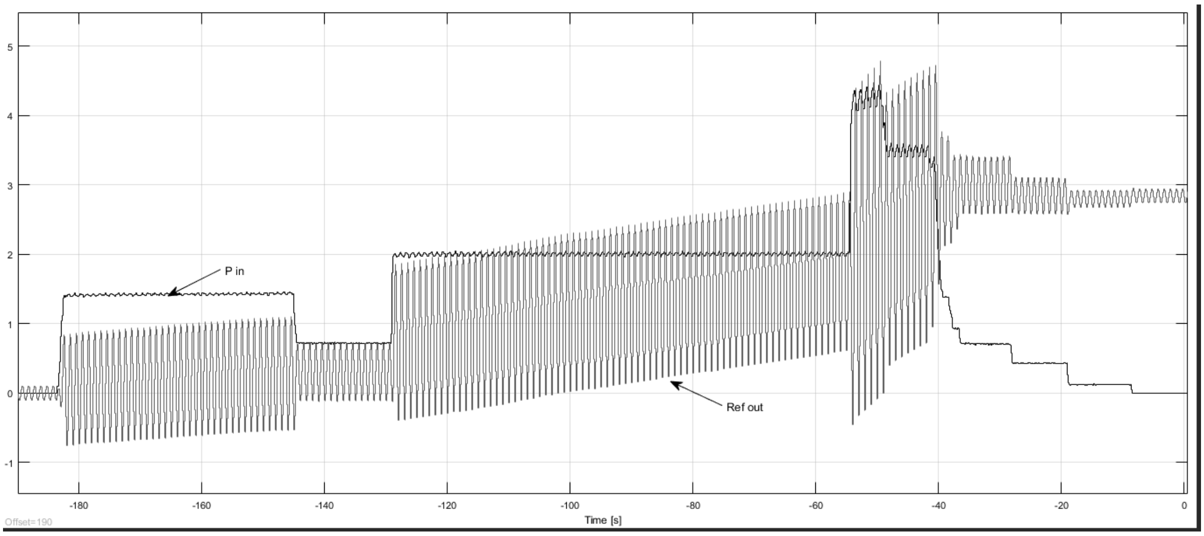

Figure 9. The waveforms for input signal P_in, respectively the reference signal Ref_out (the control signal of the DC-DC converter) for the condition 1 of Table 2

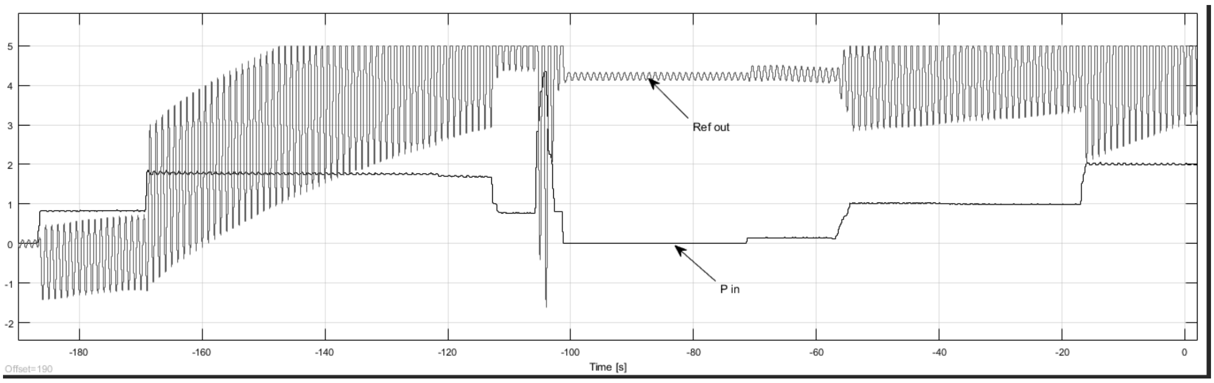

Figure 10. The waveforms for input signal P_in, respectively the reference signal Ref_out (the control signal of the DC-DC converter) for the condition 2 of Table 2

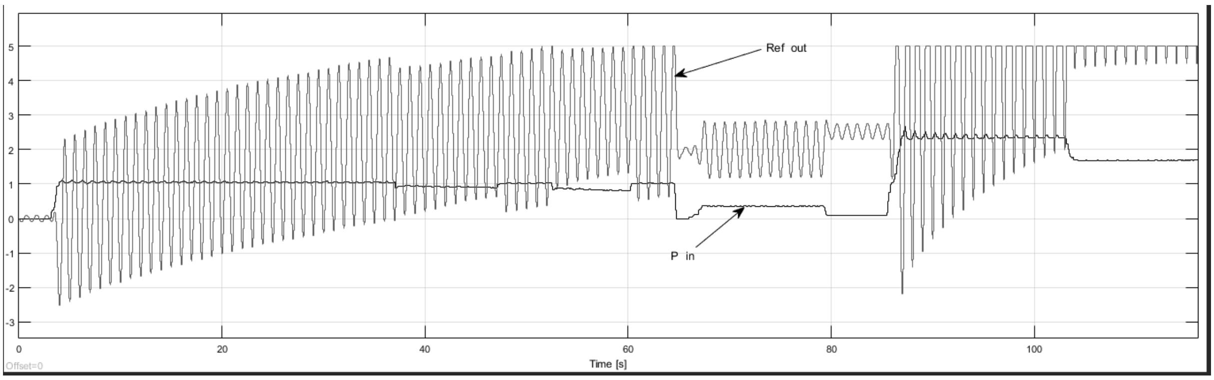

Figure 11. The waveforms for input signal P_in, respectively the reference signal Ref_out (the control signal of the dc-dc converter) for the condition 3 of Table 2

Waveform of output signal from ESC algorithm (Ref_out) is transformed by a specialized module of microcontroller in a PWM signal with duty cycle proportional to its value.

The input signal *P_in* was change with controllable power source to highlight the tracking feature. In this case the control signal, Ref_out, controls the DC-DC power converter to harvest the maximum power by tracking the levels of the input signal *P_in*.

Due to the saturation block (LIM2), the Ref_out signal is limited to the value +5 (see Figures 10, 11). Figure 10 shows that the MPP search speed increases when the value of K1 is increased. Also, Figure 11 shows that the search speed increases if the value of KA is increased, validating the simulation shown in figure 5.

IV. CONCLUSION

In this paper was presented and analyzed an optimized solution for long-term supply of a system for the protection of critical infrastructures. The solution adopted here for the MPP search of photovoltaic panel is based on the ESC algorithm.

The simulation results presented in second section of the paper have shown the performance of this ESC algorithm in MPP searching and tracking. That leads to a high energy efficiency and lifetime for the power systems powered by PV panel, with a low maintenance [15].

The experimental results presented in third section have validated the theoretical assumptions and simulation results. For a more deep analysis of the energy efficiency of the PV system based on ESC algorithm, the experiment must be repeated for higher power levels (order of kW).

The ESC algorithm control parameters can be easily tuned to obtain better results by using PIL technology.

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REFERENCES

[1] Iana Vasile Gabriel, Petre Anghelescu, Vibration monitoring system for human activity detection, Int conf on Electronics, Computers and Artificial Intelligence – ECAI 2015; Vol. 7, no. 2/ 2015 ISSN: 1843 – 2115

[2] Petre Anghelescu, Gabriel Vasile Iana, Ionut Tramandan, Human footstep detection using seismic sensors, Int conf on Electronics, Computers and Artificial Intelligence – ECAI 2015; Vol. 7, no. 2/ 2015 ISSN: 1843 – 2115

[3] Hoarca IC, Raducu M. On the micro-inverter performance based on three MPPT controllers. Journal of Electrical Engineering, Electronics, Control and Computer Science - JEEECCS 2015 1(1):7-14; (available on http://jeeeccs.net/index.php/journal/article/view/9)

[4] Molaei S, Jalilzadeh S, Mokhtarifard M. A new controlling method for maximum power point tracking in photovoltaic systems. IJTPE 2015;7(1):1-7 (available on http://www.iotpe.com/IJTPE/IJTPE-2015/IJTPE-Issue22-Vol7-No1-Mar2015/1-IJTPE-Issue22-Vol7-No1-Mar2015-pp1-7.pdf).

[5] Mihaescu M. Applications of multiport converters. Journal of Electrical Engineering, Electronics, Control and Computer Science - JEEECCS 2016 2(1):13-18; (available on http://jeeeccs.net/index.php/journal/article/view/25)

[6] Bizon N. Global Extremum Seeking Control of the Power Generated by a Photovoltaic Array under Partially Shaded Conditions, Energy Conversion and Management 2016;109:71-85.

[7] Bizon N. Global Maximum Power Point Tracking based on new Extremum Seeking Control scheme, Progress in Photovoltaics: Research and Applications 2016;24(5):600-22.

[8] M.C. Di Piazza, G. Vitale, Photovoltaic field emulation including dynamic and parţial shadow conditions, Applied Energy 87 (2010), 814–823.

[9] T. Esram, P.L. Chapman, Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques, IEEE TRANSACTIONS ON ENERGY CONVERSION 22 (2) (2007), 439 - 449 .

[10] Roberto Faranda, Sonia Leva, Energy comparison of MPPT techniques for PV Systems, WSEAS TRANSACTIONS on POWER SYSTEMS 6(3) (2008), 448-450

[11] Oproescu M, Raducu M, Constantinescu LM, Ramos-Hernanz JA, Lopez-Guede JM. Evaluation of the performance of new extremum seeking control algorithm to locate accurately the peaks on multimodal functions. Int conf on Electronics, Computers and Artificial Intelligence – ECAI 2016; 10.1109/ECAI.2016.7861153.

[12] Bizon N, Thounthong P, Raducu M, Constantinescu LM. Designing and modelling of the asymptotic perturbed extremum seeking control scheme for tracking the global extreme. Int J Hydrogen Energ 2017; http://dx.doi.org/10.1016/j.ijhydene.2017.01.086.

[13] Bizon N., Energy harvesting from the PV Hybrid Power Source, Energy 52 (2013): 297–307.

[14] H. Erdem, E. O. Tartan, A. Berkol. Application of three intelligent methods for harmonic estimation: Adaline, Adaline-LS, PSO-LS. Journal of Electrical Engineering, Electronics, Control and Computer Science - JEEECCS 2015 1(1);1-6; http://jeeeccs.net/index.php/journal/article/view/7

[15] George Robert Şişman, Mihai Oproescu. Predictive maintenance of power industrial electronic equipment. Journal of Electrical Engineering, Electronics, Control and Computer Science - JEEECCS 2015 1(2);21-30; http://jeeeccs.net/index.php/journal/article/view/18