dSPACE Implementation for a Fuzzy Logic Voltage Control using a Self-Excited Induction Generator and a Voltage Source Inverter

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Article Info	ABSTRACT
	The present work describes the analysis of a control scheme for keeping the RMS voltage output constant, the system is supplying by a self-excited induction generator with variable speed and load. A comparison is examined between simulation and experimental results using dSPACE board. The results are provided to verify the effectiveness of this approach and gives very high performance.

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1. INTRODUCTION

Energy production using renewable natural resources such as the wind has became an obligation in recent years account their positive effects, especially in remote areas where the self-excited induction generator (SEIG) is the most used[1].

The difficulty of the use of this kind of generator are the regulation and control of frequency and voltage, and also the very bad power factor.

There is some parameters that influences the variation and the change of magnitude of voltage produced by the generator and the frequency which are the rotor speed, the capacitance of excitation and the change of load [2] to solve this problem, Several studies were dedicated [3] by using an advanced power electronic converters, all the variable parameters (voltage and frequency) in the output of the SEIG are converted into constant values.

This configuration uses different sources of direct current, which is considered an advantage for applications with renewable energy sources since it allows generating different voltage levels at the output to suit the use. However this still has limitations namely the imbalance of power between the generator versus consumption.

The disadvantage of Three-phase source inverter (VSI) is the THD voltage (Total harmonic distortion) [4] this value should not go over 5 per cent, according to the guidelines of the IEEE Standard 519-1992. Generally, there are many ways to generate a voltage output with low distortion. among these methods are mentioned series and shunt compensation or hybrid series active power filters which can be used

for the exclusion of harmonics when nonlinear loads [5] are coupled to a VSI [6], [7]. On the other hand, we can use the optimum fixed LC compensator, which is considered to reduce the expected value of the total THD, while it is highly preferable to keep a specific value of the power factor (PF) [8], [9]

Another constraint is added, it is the great variability of wind speed in the case of a wind power plant and the change of solar radiation in the case of a photovoltaic plant this obviously affects the quality of the energy which will cause major disruptions on the connected load. The VSI proposed may be the solution to generate electricity of good quality despite these disturbances. This kind of converter has been much recent interest in recent years and this is especially due to the large number of its advantages in practice.

The research that preceded this work, deals with many control techniques for generating the output voltage with a good quality and without distortions, purely a sinusoidal waveforms. First, in [10] a classical proportional-integral (PI) controller was investigated and secondly a PI-derivative (PID) controllers for the single-phase inverter was treated in [11].

In this context, the present work concerns a stand-alone system based on a voltage source inverter and feeding by a SEIG then we present a experimental study of the system performance.

The three phase full bridge diode rectifier is feeding by the voltage output of the SEIG and converts the alternative power to a variable DC voltage. The effect of the wind is represented by the prime mover which also leads to a variable RMS output voltage of the inverter.The objective is to regulate the output voltage by using the closed-loop control scheme that why a fuzzy logic (FL) PI controller is considered to obtain the appropriate modulation index (mi) used in sinusoidal pulse-width modulation (SPWM), and finally we create the different permutation which can take the VSI. The output of the system contains a lot of distortions and the THD is very haigh. So, we connect a passive filter before transferring power to the loads [12].

The outline of this paper is done as the following: in first section we talk about the system configuration and we propose the FL PI regulator used with the SPWM switching scheme. In the second section, the simulation, the experimental results and the corresponding analysis are presented. Finally, in the last section we end up this paper with a conclusion.

2. SYSTEM CONFIGURATION

In this section we present the stand-alone generator, which is designed for feeding a three phase load, Figure 1 shows a schematic of our system.

The pargraphes below discuss mathematical equations that model the components of the system considered namely the SEIG, AC/DC converter, the VSI and LC filter.
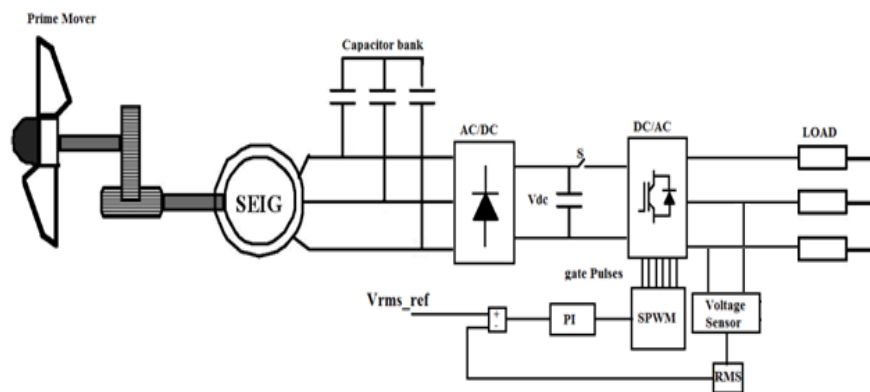

Figure 1. Configuration of the proposed system

2.1. SEIG Mathematical Model

Practically we consider the dynamic model of the SEIG. It can be calculated from the classical model by modifying the conventional dynamic equations of an AC machine, this is presented in the works of M. Basic [13]. The classic dynamic model SEIG expressed in the Laplace domain and suitable for use in MATLAB Simulink is described in the stationary reference frame by the following 1 differential Order:

$$
\begin{cases}
si_{s\alpha} = \dfrac{1}{\sigma L_s L_r}(L_m^2 \omega_r i_{s\beta} - L_r R_s i_{s\alpha} + L_m \omega_r L_r i_{r\beta} + L_m R_r i_{r\alpha} - L_r u_{s\alpha} - L_m K_{r\alpha}) \\[2mm]
si_{s\beta} = \dfrac{1}{\sigma L_s L_r}(-L_r R_s i_{s\beta} - L_m^2 \omega_r i_{s\alpha} + L_m R_r i_{r\beta} - L_m \omega_r L_r i_{r\alpha} - L_r u_{s\beta} - L_m K_{r\beta}) \\[2mm]
si_{r\alpha} = \dfrac{1}{\sigma L_s L_r}(L_m R_s i_{s\alpha} - L_s \omega_r L_m i_{s\beta} - L_s \omega_r L_r i_{r\beta} - L_s R_r i_{r\alpha} + L_m u_{s\alpha} - L_s K_{r\alpha}) \\[2mm]
si_{r\beta} = \dfrac{1}{\sigma L_s L_r}(L_m R_s i_{s\beta} + L_s \omega_r L_m i_{s\alpha} - L_s R_r i_{r\beta} + L_s \omega_r L_r i_{r\alpha} + L_m u_{s\beta} - L_s K_{r\beta})
\end{cases}
\tag{1}
$$

where:

a. $u_{s\alpha}$ and $u_{s\beta}$ are the α-axis and β-axis component of the stator phase voltage space-vector;

b. $i_{s\alpha}$ and $i_{s\beta}$ are the α-axis and β-axis component of the stator phase current space-vector;

c. $i_{r\alpha}$ and $i_{r\beta}$ are the α-axis and β-axis component of the rotor phase current space-vector;

d. R_s and R_r are the stator and rotor resistance, respectively;

e. L_s, L_r and L_m are the stator inductance, the rotor inductance and the magnetizing inductance, respectively;

f. ω_r is the rotor angular speed;

g. σ is the total leakage factor;

h. $K_{r\alpha}$ and $K_{r\beta}$ are the α-axis and β-axis component of the voltage initially induced due to the residual rotor flux linkage.
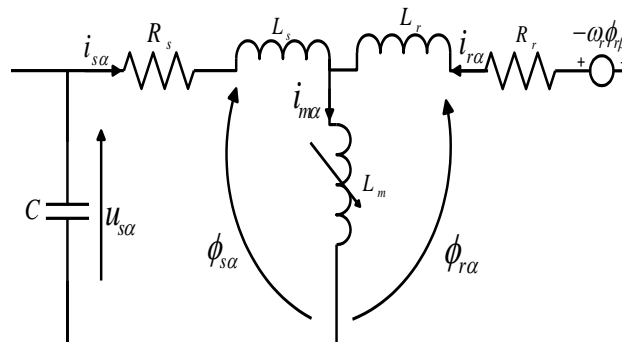

Figure 2. The Equivalent Schematic of the SEIG

The equation that describe the voltage in the DC link is:

$$
u_{dc} = -\frac{1}{C}\int_0^t i_{dc}\,dt + u_{dc0}
\tag{2}
$$

Figure 2 shows the conventional SEIG equivalent circuit described by (1).

An experimental test of the machine object of the study was has given magnetization curve which represents The variation of magnetizing inductance (Lm) in function of phase voltage for induction machine [14].

2.2. Three Phase AC/DC Converter

A rectifier is an electrical machine that transfers AC current, which has a sinusoidal waveforms, to DC current, which flows in only one direction. The circuit is composed of 6 diodes: a group of three in the top and a group of three in the bottom as shown in Figure 3.
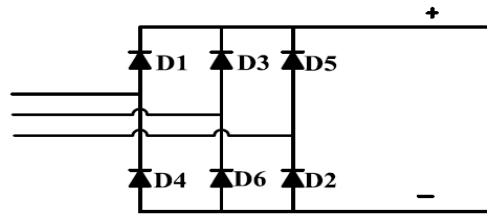
Figure 3. Three-phase AC/DC converter

2.3. Three-phase Source Voltage Inverter

A power inverter, is an electronic device that converts DC current toAC current. The VSI has three-switching states as described in Table 1, obtained by different permutations of the six switches Sa, Sb, Sc, Sa', Sb' and Sc'.

For supplying the power to the loads. We use a three voltage source inverter which is represented in the Figure 4, It is used to generate and keep the alternating output voltage at a fixed value (220 Vrms) , with 50 Hz frequency and with differents types of loads in isolated power generation systems. We note that the outputs (voltage and current) depends on the scheme of the control permutations state outputs.
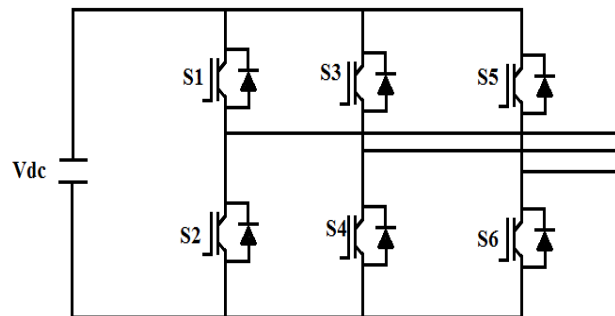

Figure 4. Three-phase DC/AC inverter

Table 1. The switching statesof the inverter

Sa	Sb	Sc	Sa'	Sb'	Sc'	Uab	Ubc	Uca
1	0	1	0	1	0	0	0	0
0	1	0	1	1	0	0	-Udc	Udc
1	0	0	1	1	0	Udc	-Udc	0
0	1	1	0	1	0	-Udc	0	Udc
1	0	1	0	0	1	0	Udc	-Udc
0	1	0	1	0	1	0	0	0
1	0	0	1	0	1	Udc	0	-Udc
0	1	1	0	0	1	-Udc	Udc	0

3. PROPOSED SCHEME OF CONTROL: PI REGULATOR CONNECTED WITH THE SPWM PERMUTATIONS

The main of this section is to define the scheme of control employed in the three-phase inverter in the stand-alone power generation system, so we use a Fuzzy logic Proportional-Integral regulator wich controls a SPWM switching. The Figure 4 represents the proposed configuration to regulate and keep the output voltage at 220 Vrms in different uses (change of loads) with a 50 Hz constant frequency, [15].

Figure 5 illustrates the Simulink model of the proposed controller. It's composed from a 3-level PWM inverter with sinusoidal modulation, then we compare the control signal at a desired output frequency with multilevel triangular waveforms [16-17].

In this study, we develope two different-type fuzzy logic voltage controller: Mamdani-type and Sugeno. Both of them have the same number of inputs (the error (E) and change of error (dE)), outpus and fuzzy rules.
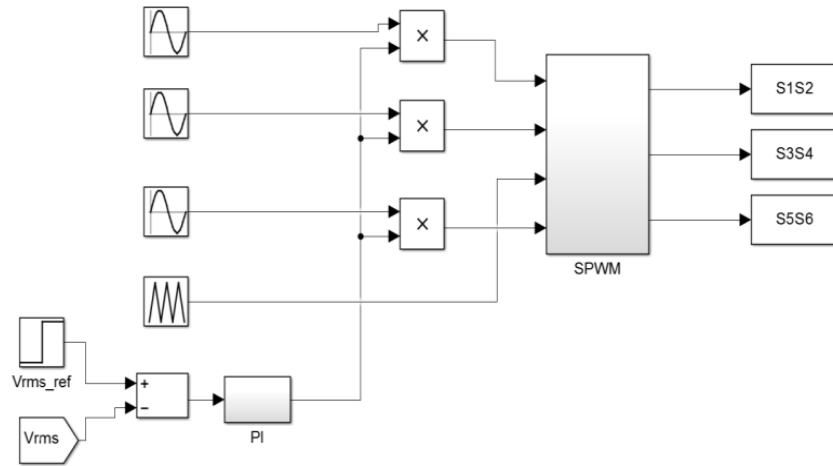
Figure 5. Proposed scheme of control: PI controller connected with SPWM

In Table 2 we give the fuzzy rules bases of the Sugeno-Type FL controller and we use the following fuzzy sets: **ZR** zero, **PS** positive small, **PM** positive medium and **PL** positive large, **NL** negative large, **NM** negative medium, **NS** negative small. For example, according to the combinations of Table 1 that the first rule is:**IF E** is **NM** and **dE** is **NM** then **du** is **NL**. The linguistic rules are in the form of **IF-THEN** rules and take form: **IF** (**E** is **A** and **dE** is **B**) **THEN** (**du** is **C**), where **A**, **B**, **C** are fuzzy subsets for the universe of discourse of the error, change of error and change of the output. For example, **B** can signify the subset **POSITIVE LARGE** of the change of error etc.

Table 2. Fuzzy Rules Bases

E/dE	NL	NM	NS	ZR	PS	PM	PL
PL	ZR	PS	PM	PL	PL	PL	PL
PM	NS	ZR	PS	PM	PL	PL	PL
PS	NM	NS	ZR	PS	PM	PL	PL
ZR	NL	NM	NS	ZR	PS	PM	PL
NS	NL	NL	NM	NS	ZR	PS	PM
NM	NL	NL	NL	NM	NS	ZR	PS
NL	NL	NL	NL	NL	NM	NS	ZR

4. PERFORMANCE ANALYSIS OF THE SIMULATION RESULTS

To test the success of the proposed study, the stand alone generation system is experienced when the different kind of constraint: the variation in the wind speed; and step change in the load.

The appendix gives different conditions taken in the simulation.

4.1. Response of the Sysem under the Variation of the Wind Speed

To start excitation we use a capacitors bank of 50μF, We carried out the simulations of the following operating regime: we change the wind speed respectively from 1000 rpm, 1100 rpm and 1200 rpm at 0, 5s and 8 s, Figure 6, show the output variation of the RMS voltage, as we can see the terminal voltage were notably maintained constant at 220 Vrms, despite the change in rotor speed of the SEIG.
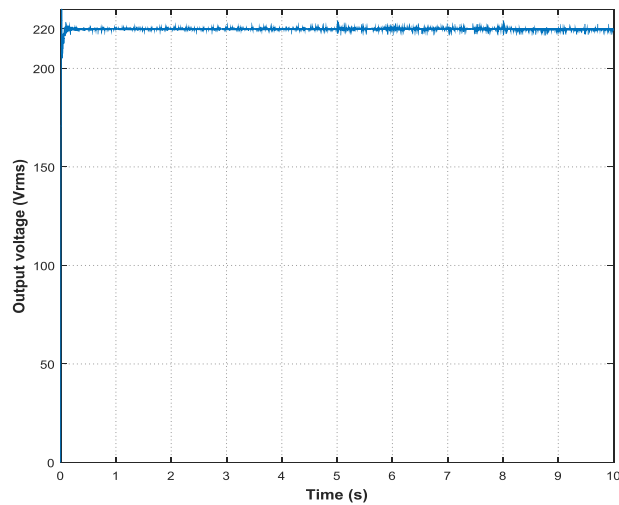
Figure 6. Output voltage (Vrms) under rotor speed change

4.2. Response of the Sysem under the Variation of the Load

The result obtained from running simulation are shown in Figure 7, the performance of the system is tested under load variation (a resistive load) with a rotor speed variation of 1200 rpm. Then we keep the load at constant value and we change the set.

As we can see the output voltage while the variation of the resistive load during the time from 0 s to 10 s. The simulation results show that the output voltage reach a steady state after 5 s onwards. Initially, the resistive load of 500 W is connected to the inverter. This load is then changed to 1 KW at 8 s. So we can confirm that the proposed controller is working adequately to keep the system output voltage magnitude at 220 Vrms with minimal ondulations.
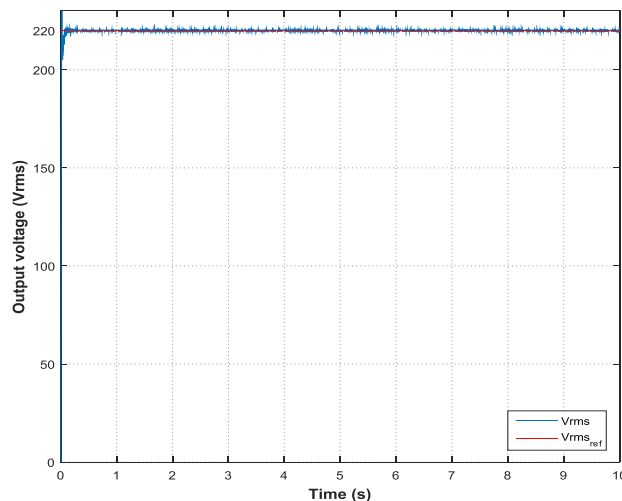
Figure 7. Output voltage (Vrms) under load change from 500 W to 1 KW

4.3. Set Change under Load Condition

In this test we keep the load at 500 W, then we change the reference value of Vrms at 110 V, 220 V, 140 V and 90 V. Figure 8 shows the output voltage (Vrms) when the set change

Again we confirm that the proposed PI controller shows its strength to control the magnitude of the output voltage of standalone generator to the desired value in the right conditions of rapidity and accuracy.
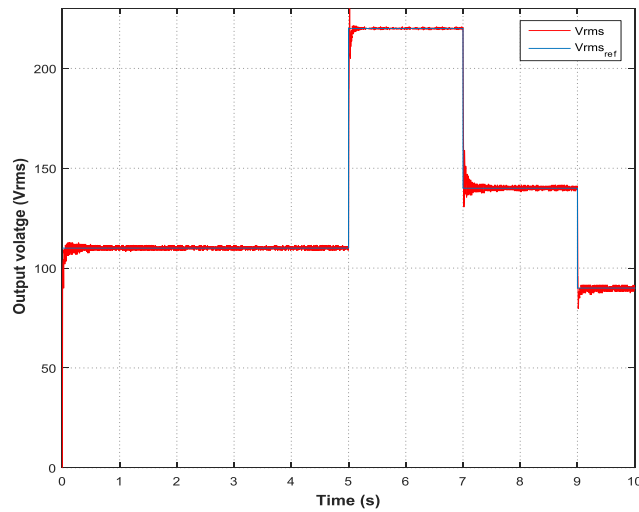
Figure 8. The output voltage (Vrms) when the set change

5. EXPERIMENTAL RESULTS

In order to test the results achieved in the previons section a dSPACE board with TMS320F240 DSP is used (Figure 9). The dSPACE works on Matlab/Simulink platform.

To view the signals, we use Control Disc software associated to dSPACE card. The protocol that provides communication between the computer and the card is a model DS1104.

Simulink Matlab developed and activated by a GUI ControlDesk. This software allows us to see the different variables of the system to be controlled in real time.

It should be noted that the ControlDesk, offers the possibility to save the variables of the system .mat formats, allowing us to do post processing on these variables.

The induction generator used in this experimental investigation is a three phases, 3KW, 4 poles squirrel cage, 7.2A/12.5A, 220V/380V, 50HZ and 1400rpm.

A DC motor is used to drive the SEIG. Its characteristics are: 3KW, 120V, 25A and 1500rpm.

In addition, all of the measured quantities (current and voltage) were collected using LEM sensors (LEM HX15-P, LEM LV25-P), and both of them are then transformed to be a voltage ranging from 0 to ±10 volts which will be the input of A/D respectively.

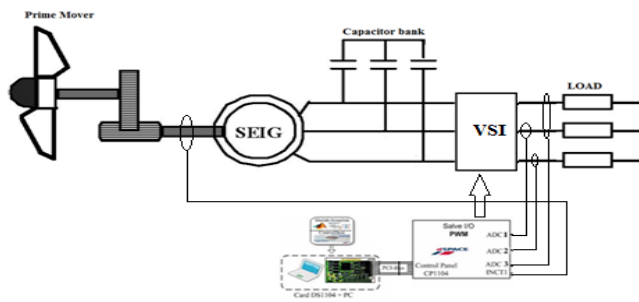The SEIG experimental setup is presented in Figure 10:

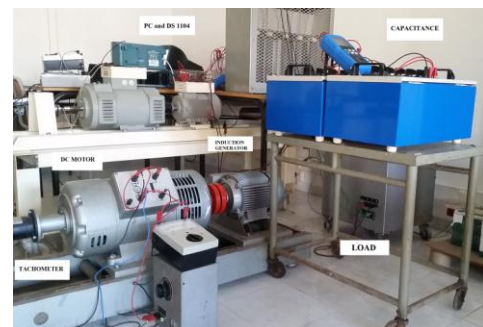Figure 9. The experimental test setup

Figure 10. Photograph of the experimental setup

5.1. Effect of the wind Speed

In order to verify the effect of the wind we apply the rotor speed such as illustrated in Figure 11. The Figures 12-14 shows the obtained results, it can be observed that the proposed Fuzzy logic (FL) PI controller maintain the Vrms at 110 Vrms and the output voltage and current waveforms change according to the speed profile.
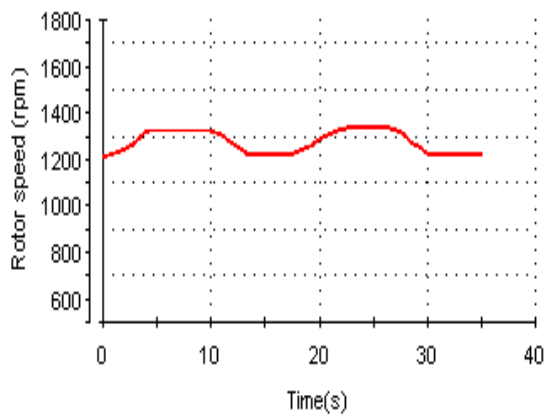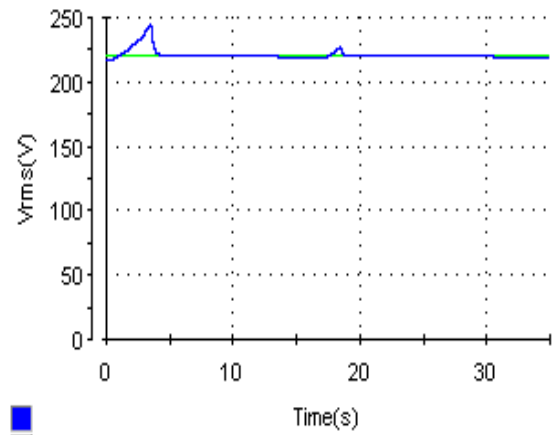
Figure 11. The speed of rotor variation

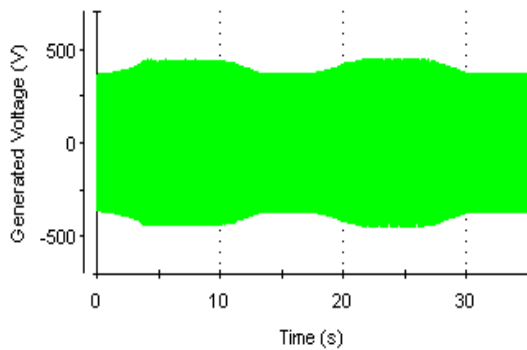Figure 12. The RMS value of the output voltage
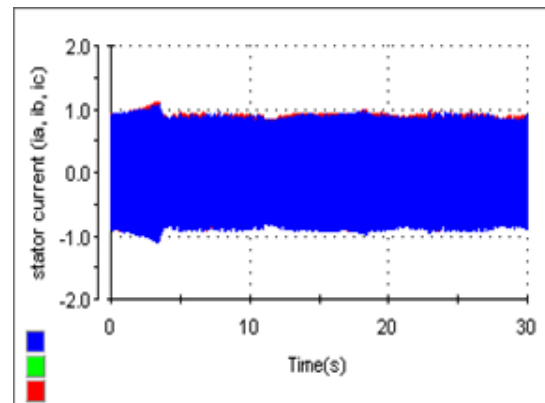

Figure 13. The generated voltage of SEIG

Figure 14. The generated current of SEIG

5.2. Step Change in the Set

The induction generator rotates at a 1150rpm (Figure 15), then we change reference of Vrms according to the following values: 80 V and 110 V at 0 s and 10.

The Figure 16 shows the measured Vrms in the output of the VSI and in Figures 17 and 18 we observe the generated voltage and current, as we can see the Vrms signal follows the set and the presented control gives the best results in terms of speed and accuracy.
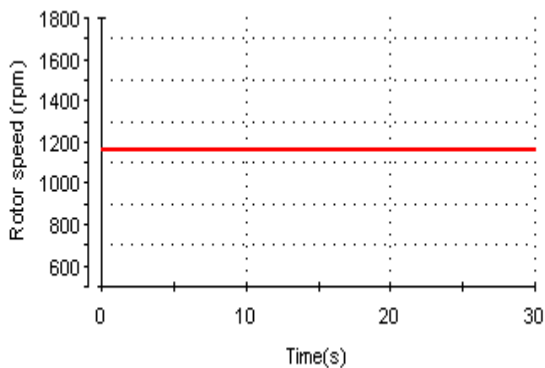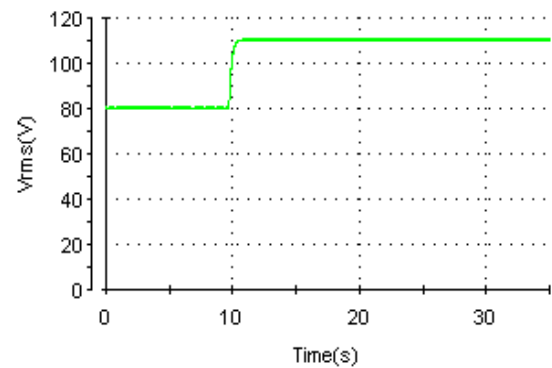

Figure 15. The speed of rotor variation

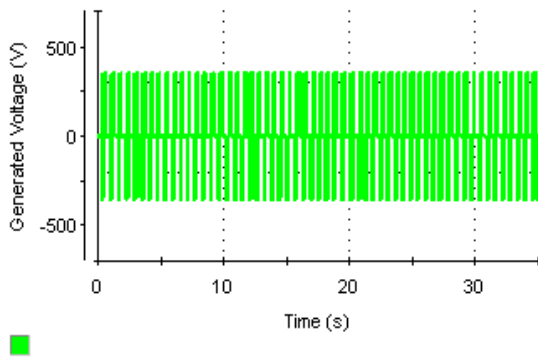Figure 16. The output voltage under change of the set
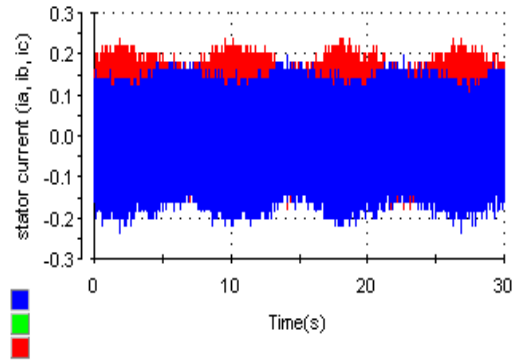
Figure 17. The generated Voltage of SEIG

Figure 18. The generated current of SEIG

5.3. Effect of the Load Change

To verify the effect of load variation on the proposed control, we adopt functioning no load and then applying a resistive load 500 W at 3 s. As can be seen, the output voltage decreases (Figure 19-21) and the output current of the load when the value of load increases, while the Vrms saved at a fixed value of around 220 V regardless of perturbation of source and application of loads.
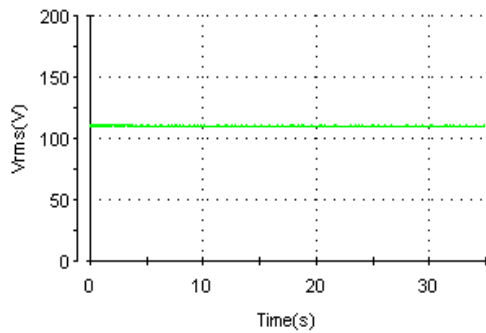

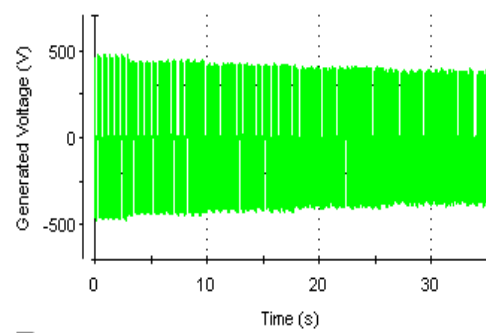Figure 19. The Vrms output voltage during load variation

Figure 20. The generated Voltage of SEIG during load variation
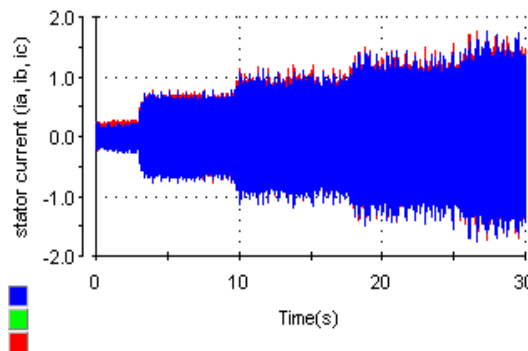

Figure 21. The generated current of SEIG during load variation

6. CONCLUSION

In This study we are investigating a three-phase system powered by three-phase voltage inverter which uses as an energy source asynchronous generator running in standalone mode, the control system proposed is based on a simple PI controller. In this issue, we evaluated the performance of the voltage

regulation system under several constraints, so we analyse the effect of the variation of the wind speed represented here by the change of the rotor speed and also the effect of the variation the AC load. The graphs obtained in the simulation confirms that the controller shows its robustness and strenght characteristics in keeping the output voltage at the desired value to feed the power for a variety of loads. The dSPACE experimental results was presented to confirm the simulation results obtained above. Our next study is to compare the proposed controller performance with a fuzzy logic controller under the same experimental conditions.

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APPENDIX

Table 3. Induction Generator Parameters

Rated power	3KW
Voltage	380V Y
Frequency	50 Hz
Pair pole	2
Rated speed	1400 rpm
Stator resistance	1.7 Ω
Rotor resistance	2.68 Ω
Inductance stator	229 mH
Inductance rotor	229 mH
Mutual inductance	217 mH
Moment of lnertia	0.046 kg.m2
Filter inductance	33,9 mH
Filter capacitance	310 mF