Research Journal of Physical Sciences ISSN 2320–4796
Vol. **7(3),** 1-6, September **(2019)** *Res. J. Physical Sci.*

Spectral content analysis of control water pumping system connected to the Electrical distribution network

Noma Talibi Soumaïla[1], Boureima Seibou[2], Adekunlé Akim Salami[3*] and Agbassou Guenoukpati[3]
[1]University Abdou Moumouni of Niamey, Niger
[2]Mines, Industry and Geology school of Niamey, Niger
[3]Electrical Engineering Department, National Engineering School, University of Lome, Togo
akim_salami@yahoo.fr

Available online at: www.isca.in, www.isca.me
Received 8th March 2019, revised 21st July 2019, accepted 20th August 2019

Abstract

The heavy use of non-linear loads generates voltage and current harmonics that can cause various disturbing problems. The objective of this paper is to evaluate the harmonic pollution caused by the equipment of an induction motor pump unit supplied by the electrical distribution network and to propose solutions to mitigate it. In this work, two pump motor starting modes, direct starting and the motor associated with an inverter controlled by PWM signals, were simulated and experimentally tested. The simulations were carried out under Matlab/Simulink environment. Simulation results and experimental tests show that starting an induction motor in combination with a PWM inverter has better electromechanical performance than the results obtained when the motor pump is fed directly from the electrical grid.

Keywords: Induction motor, inverter, electrical grid, harmonic pollution, PWM, THD.

Introduction

For many years, electricity distributors have been striving to guarantee the quality of electricity supplied. Any electrical energy generator supplies energy to user equipment through the voltages it maintains at their terminals, it is obvious that the quality of this energy depends on the quality of the voltage at the delivery point. This voltage is generally subject to many disruptions from two distinct origins: voltage disturbances caused by the passage, in the electricity networks, of disturbance currents such as harmonic, unbalanced and reactive currents and voltage disturbances caused by disturbing voltages such as voltages harmonics and unbalanced and voltage dips[1-3]. The problem of harmonics, also called harmonic pollution, is not a new phenomenon. It is currently the work of several research groups active in the field of improving the quality of electrical energy degraded by the large number of non-linear loads connected to the electricity grid[4]. These non-linear charges such as computers, fax machines, discharge lamps, arc furnaces, battery chargers, electronic power systems, electronic power supplies, electric motors, etc., cause distortion in the current, and therefore in the voltage, which can lead to malfunction of the devices connected to the network. Hence, the interest of eliminating these harmonics[1,5,6]. Our study device is an induction motor driving a water pump. By its construction, the induction motor is a non-linear load. In order to increase the electromechanical performance, an improvement is proposed in this paper. Similar studies are carried out in the literature[7,8]. The contribution of this paper consists in evaluating the consequences of harmonic effects on the electrical parameters that can influence the energy efficiency of the motor.

After a theoretical study on harmonics and control of the induction motor, we simulated in Simulink/Matlab the direct starting of the motor from the electrical grid and then via a PWM voltage inverter. Finally, we set up an experimental measurement bench to confirm the simulation results. The results obtained are satisfactory and promising.

Materials and methods

Description of the experimental set-up: We have a laboratory measurement bench including: i. A desktop computer for the acquisition of measurements; ii. A three-phase 380V/50Hz power supply between phases; iii. An INTERDAB motor, with a nominal power of 2.2kW, a nominal current of 5.6A and a nominal voltage between phases of 380 V; iv. A centrifugal pump, directly fixed on the motor shaft, representing the motor load. It allows water to be pumped from the lower basin to the upper basin (the castle) with a nominal flow rate of 110 l/min; v. An incremental encoder mechanically linked to the motor shaft that drives it. Its axis rotates a disc that is solidarity with it. The disc has a succession of opaque and transparent parts. Light emitted by light-emitting diodes passes through the slots of this disc creating an analog signal on the receiving photodiodes. This signal is amplified and then converted into a square signal, which is transmitted to a processing system; vi. A MITSUBISHI inverter, FR-E740-120SC-EC range, connected to the electrical network; vii. A DIRIS A40 from SOCOMEC, a multi-meter device for measuring electrical quantities. It can measure currents, voltages, powers (active, reactive and apparent), frequency, power factor and harmonics of high voltage and low voltage single-phase, two-phase or three-phase networks; viii. A

Tektronix digital memory oscilloscope of the TDS1001B range characterized by a bandwidth of 40MHz, a maximum sampling frequency of 2G samples/s on 2 channels. It allows the start current and steady state current spectrum to be displayed on a monochromatic LCD display. The particular interest of this device is that it allows to store removable data via a USB port on the front panel; ix. An AC 1050 current sensor allowing to observe, in real time, the pace as well as the current spectrum; x. A burket brand flow meter with 12-36V/0.7A characteristics to control the flow of water at the pump outlet.

Figure-1 is a synoptic diagram of the experimental set-up.

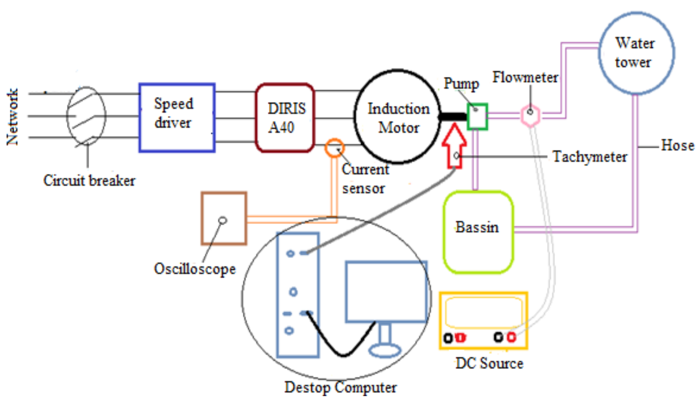

Figure-1: Overview of the experimental set-up.

Modelling of induction motor: In theory, these motors generate sinusoidal waves, but in particular they generate certain harmonics. The harmonics encountered are explained by the fact that for reasons economic, the motors are not optimized in relation to the harmonic current content. In the domestic and tertiary sector, several devices operate with induction motors, the latter, being connected to the electrical distribution networks, require capacitors for starting to compensate for the power factor[6,9]. High power motors produce less harmonics than low powers motors. The equivalent diagram of phase of induction machine brought back to the stator is shown in Figure-2. It can be simplified if the quantities to which we apply it are not the fundamental quantities but their harmonics. Indeed, the slip is expressed as a function of the pulsation of the rotating field w_s and that of the rotation of the rotor w_m as follows[10]:

$$g = \frac{w_s - w_m}{w_s} \quad (1)$$

This allows to deduce the slip corresponding to the rotating field resulting from the harmonic of rank k, and pulsation **+kw_s** or **-kw_s** according to the phase of the harmonic[11].

$$g_k = \frac{\pm k.w_s - w_m}{\pm k.w_s} \quad (2)$$

In normal operation, the pulse w_m is close to that of the rotating field w_s and the slip g is low. It can therefore be considered that for harmonics and even those of lower rank in the case of balanced signals ($k \geq 5$), the slip g_k is close to 1. In this case, the expression r'_2/g_k becomes weak in front the reactance $Kl'_2 w_s$, l'$_2$ is then in parallel with L_{10}. We will also admit it, to simplify, that R_s can be neglected. For harmonics, the equivalent scheme of a phase is therefore reduced to an inductance L_h[10].

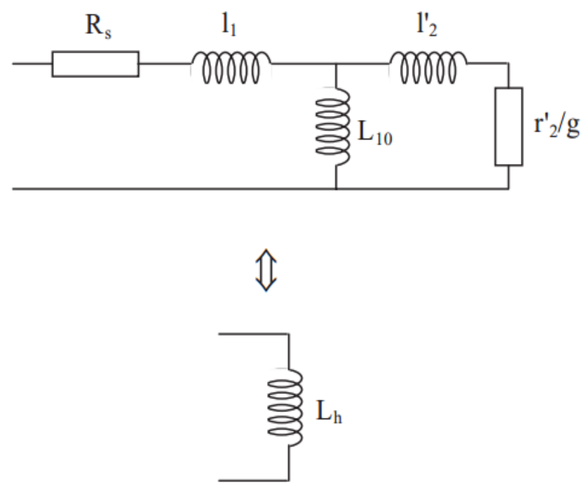

Figure-2: Simplification of the equivalent scheme of a phase of the induction machine[10].

R_s: resistance of a stator phase, l_1: stator leakage inductance, r'_2: rotor resistance brought back to the stator, l'_2: rotor leakage inductance returned to the stator, L_{10}: magnetizing inductance.

Assuming that the supply voltages are balanced, the following equations can be written:

$$\begin{cases} V_{as} = V_{smax}\cos(w_S t) \\ V_{bs} = V_{smax}\cos(w_S t - \frac{2\pi}{3}) \\ V_{cs} = V_{smax}\cos(w_S t + \frac{2\pi}{3}) \end{cases} \quad (3)$$

The simple voltages V_{as}, V_{bs} and V_{cs} applied to the three phases of the motor can be written according to the fundamental and harmonics:

$$V_{as} = V_{as1} \sum_{k\rangle 1}^{+\infty} V_{ask} \quad (4)$$

V_{ask} represents the expression of the harmonic voltage of rank k (modulus and phase), and V_{as1} the fundamental voltage applied to one of the phases. It can be deduced that the current I_h from the harmonics can be calculated from the diagram in Figure-3, knowing the equivalent inductance L_h.

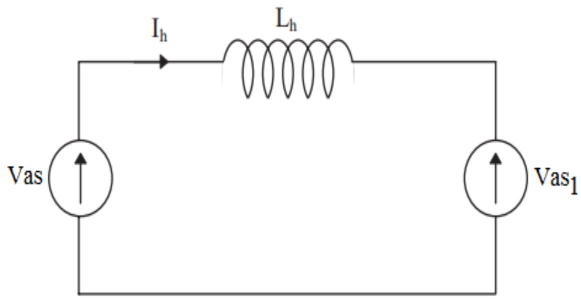

Figure-3: Calculation of the harmonic current[10].

The current due to the harmonics I_h is calculated by solving the following differential equation:

$$V_{as} = V_{as1} + L_h \frac{dI_h}{dt} \quad (5)$$

$$V_{as1} = A\sin(wt + \varphi_1) = A\sin(\alpha + \varphi_1) \quad (6)$$

Where A is the amplitude of the fundamental of the simple voltage V_{as1}; w is the pulsation of the control signal; t is the time; and α is the electrical angle. The phase current can be determined by adding to the fundamental current the current created by the harmonics. For each calculation point of I_h, the current it supplies to a phase of the motor is obtained by:

$$I_1 = I_h + I_0\sin(wt + \varphi) \quad (7)$$

Results and discussion

Comparison between simulation and experimental result: We used MATLAB software under Simulink to simulate the mathematical model. Figures-4 and 5 present the simulation results of a direct network no-load and under load.

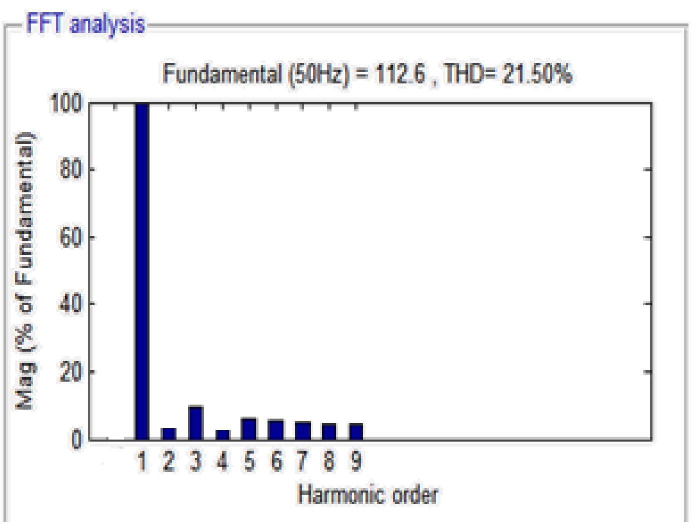

Figure-4: Simulation no-load current spectrum in direct network.

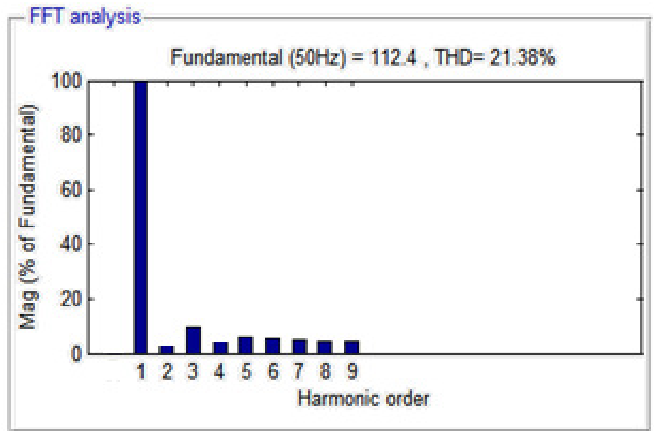

Figure-5: Simulation load Current spectrum in direct network.

Figures-6 and 7 present the experimental results of direct network with and no-load.

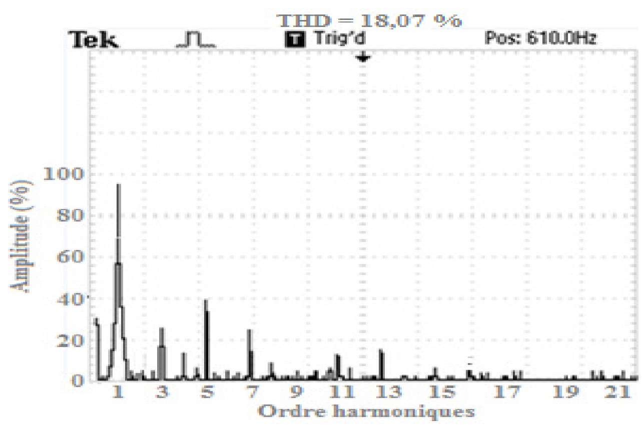

Figure-6: No-load experimental spectrum in direct network.

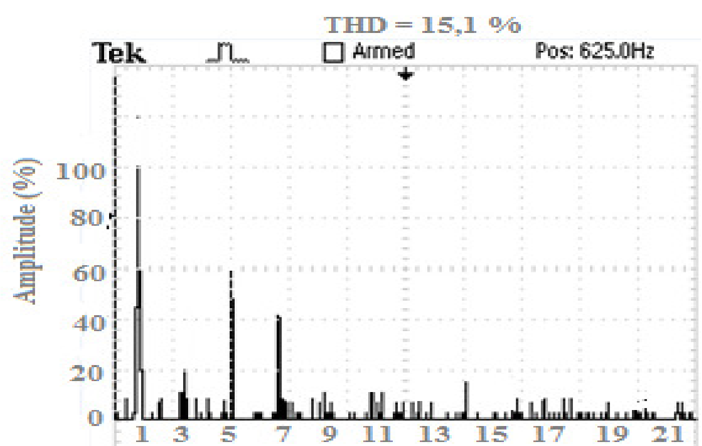

Figure-7: Load experimental spectrum in direct network.

Figures-8 and 9 present respectively, the simulation Start-up simulation results associated with the PWM inverter with and without load. The experimental results of direct with and without load are respectively presented in Figures-10 and 11. All the results obtained are summarized in Tables-1, 2, 3 and 4.

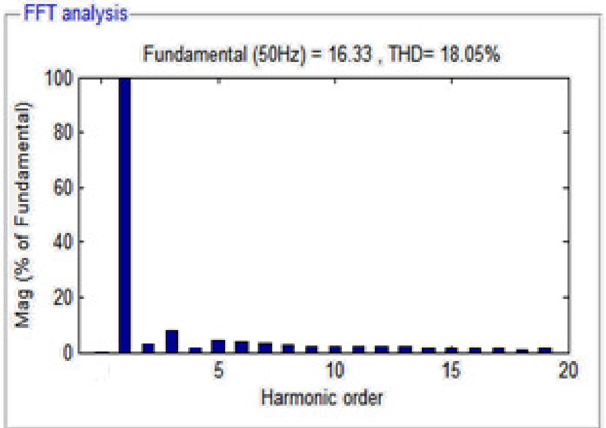

Figure-8: Simulation no-load start associated with PWM inverter.

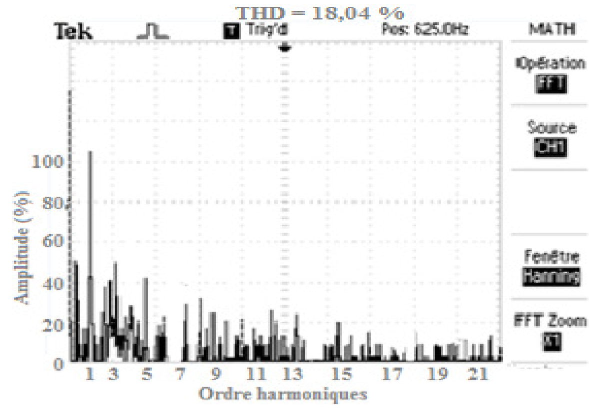

Figure-10: Experimental no-load spectrum associated with PWM inverter.

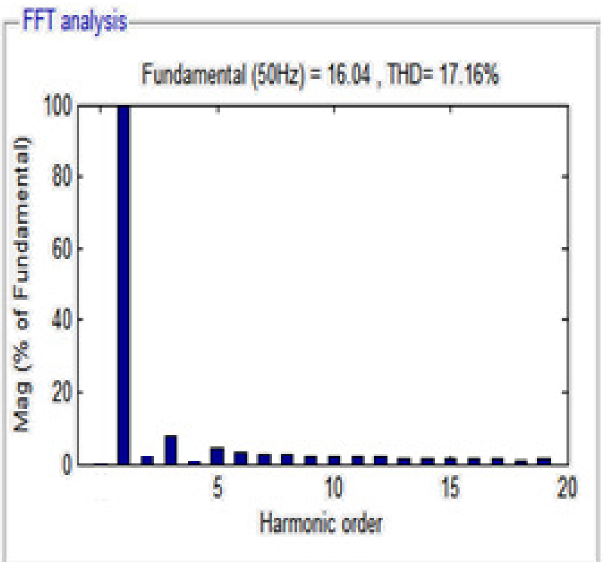

Figure-9: Simulation load start associated with PWM inverter.

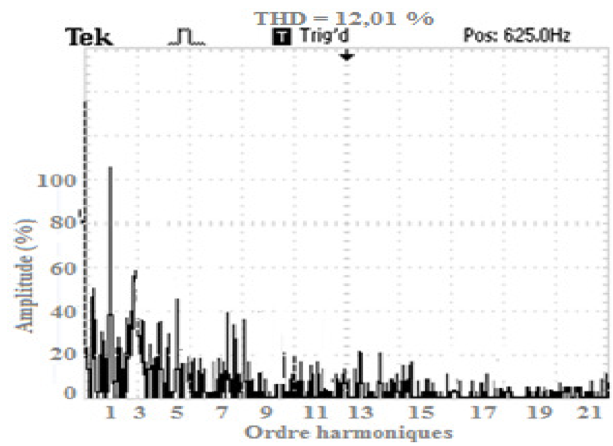

Figure-11: Load experimental spectrum associated with PWM inverter.

Table-1: Simulation and experimental surveys of harmonic levels.

Levels	Simulation		Experimentation	
	Direct connection	Associated with an MLI inverter	Direct connection	Associated with an MLI inverter
Empty	21.50%	18.05%	18.07%	18.04%
Load	21.38%	17.16%	15.10%	12.01%

Table-2: Experimental surveys of electrical and mechanical parameters.

Parameters		Stator current (A)	Power absorbed			Power factor	Pumped water flow rate (l/s)
			Active (kW)	Reactive (kVAR)	Apparent (KVA)		
Direct network	Empty	1.75	0.92	0.64	1.12	0.62	-
	Load	3.8	1.52	2.15	2.63	0.70	1.8
Associated with an	Empty	1.48	0.75	0.7	1.02	0.74	X

PWM inverter	Load	3.8	2.10	1.47	2.56	0.82	2.4

Table-3: Experimental surveys of electrical and mechanical parameters with same flow rate.

Parameters	Stator current (A)	Power absorbed			Power factor	Pumped water flow rate (l/s)
		Active (kW)	Reactive (kVAR)	Apparent (kVA)		
Direct network	3.80	1.87	1.90	2.62	0.70	1.70
Associated with an PWM inverter	2.70	1.66	1.3	2.10	0.80	1.70

Table-4: Experimental surveys of electrical and mechanical parameters with same stator current.

Parameters	Stator current (A)	Power absorbed			Power factor	Pumped water flow rate (l/s)
		Active (kW)	Reactive (kVAR)	Apparent (kVA)		
Direct network	3.05	1.38	1.45	2.00	0.69	1.30
Associated with an PWM inverter	3.05	1.58	1.22	2.00	0.79	1.61

Discussion: The simulation results are in adequacy with respect to the experimental measurements. They show that the operation of the motor fed directly from the power grid is less efficient than using a suitable PWM control. The PWM allows the motor to be powered by voltages of variable high frequencies. These voltages generate harmonics of low frequencies but high amplitudes that are easily filtered by the stator windings of the motor. Under load, there is a significant reduction in the harmonic level due to the nominal operation of the motor under load. The direct start is too inductive; the motor consumes a lot of reactive power leading to a decrease in power factor resulting in more energy losses. In addition, the THD of the control is lower than that of the direct start thanks to the presence of the motor windings which are used as filters. They eliminate all noise and harmonics, which makes the control less polluting than that of the direct start. PWM significantly improves the performance of the inverter voltage, thus avoiding the deficiencies of conventional filtering methods. These are essentially the cancellation of low-ranking harmonics and the minimization of the current distortion rate. The currents flowing in the phases of the machine in established state then have properties closer to the sinusoid, thus improving the efficiency of the installation. These results show that the PWM control is more efficient than direct start.

Conclusion

In this paper, we are interested in the spectral study of the asynchronous motor operating with direct supply to the distribution grid and then via a PWM voltage inverter. Our work focused more particularly on the analysis of the performance of the asynchronous motor in the presence of harmonics. After a bibliographical study followed by the modeling of the induction motor powered by a disturbed source, we proceeded to the simulation. An experimental measurement campaign allowed us to confirm the simulation results. A solution based on the PWM control reduces the harmonic rate caused by the non-linearity of this type of motor but also improves the efficiency of the motor. Our results are consistent with other similar studies in the literature[11-13].

References

1. Yue M.A. and Ling Z. (2007). An analysis and simulation of shunt hybrid active power filter. *Electrical Machines and Systems*, ICEMS. International Conference on, 90-93.
2. Akagi H. (2005). Active harmonic filters. Proceedings of the IEEE, 93(12), 2128-2141.
3. Collombet C., Lupin J.M. and Schonek J. (1999). Harmonic disturbances in polluted networks and their treatment. Schneider Electric, Technical Paper, No. 152, 145-150.
4. Thajeel E.M., Daniyal H., Sulaiman M.H. and Mahdi M.M. (2015). Control schemes for shunt active filters to mitigate harmonics using triangular carrier current controller. *IJESRT*, 4(8), 758-762.
5. Hoevenaars T., LeDoux K. and Colosino M. (2003). Interpreting IEEE STD 519 and meeting its harmonic limits in VFD applications. *Annual Petroleum and Chemical Industry Conference*, 50(1).
6. A. L. de Heredia Bermeo (2006). Advanced controls of systems dedicated to improving energy quality: from low voltage to voltage rise. Institut National Polytechnique of Grenoble-INPG.
7. Somendra Banerjee, Chatterjee Dr. S. and Shimi S.L. (2013). Reduction of Total Harmonics Distortion in Four Switches Three Phase Inverter Fed Induction Motor Drive. *International Journal of Research in Electrical &*

Electronics Engineering, 1(2), 82-91. www.iaster.com, ISSN Online: 2347-5439.

8. Birbir Y. and Nogay H.S. (2007). Harmonic Variations in Three-phase Induction Motors Fed by PWM Inverter with Different Stator Coil Pitches. Proceedings of the 6th WSEAS International Conference on Applications of Electrical Engineering, Istanbul, Turkey, 195-199.

9. Godfroid H. (1993). Numerical control of AC motors: needs and solutions. *General Electricity Review*, 5, 13-26.

10. Depernet D. (1995). Optimization of the control of a three-stage PWM inverter for asynchronous machines. University of Reims-Champagne Ardenne.

11. Mohammed Jamal A. (2008). Performance Improvement of a Single Phase Induction Motor Fed by Non-sinusoidal Voltages. *Eng. &Tech*, 26(7), 797-812.

12. Mohanty K.N. and Muthu R. (2010). Microcontroller based PWM controlled four switch three phase inverter fed induction motor drive. *serbian journal of electrical engineering*, 7(2), 195-204.

13. Boumaaraf A., Draou M.D. and Chikhi S.A. (2002). A New Concept of PWM Control for the Photovoltaic Pumping System. *Rev. Energ. Ren.*, 5, 139-147.