Speed Control of Induction Motor Driving a Pump Supplied by a Photovoltaic Array

Chbirik Ghizlane*‡, Zakaria Massaq*, Abdelouahed Abounada *, Mustapha MABROUKI**

*Electrical Engineering Department, Faculty of Sciences and Technology, University of Soultan Moulay Sliman, Laboratory of Automatic, Energy Conversion and Microelectronic, P.B: 523 Mghila, Beni Mellal 2300, Morocco.

** Physics Department, Faculty of Sciences and Technology, University of Soultan Moulay Sliman industrial engineering laboratory, P.B: 523 Mghila, Beni Mellal 2300, Morocco.

(Ghizlane.fst@gmail.com, zakaria.massaq@gmail.com, a.abounada@gmail.com, mus_mabrouki@yahoo.com)

G. Chbirik; P.B: 523 Mghila Beni Mellal - Morocco, Tel: +212 637521374,

Fax: +212 523 48 52 01, ghizlane.fst@gmail.com

Received: 19.12.2019 Accepted:19.02.2020

Abstract- The integration of renewable energies in electrical systems is a research area that is becoming more and more important. In this context, this work aims regulation of induction motor speed that drives a pump supplied by a photovoltaic array. The objective of this study is to calculate the reference speed corresponding to the maximum power supplied by the photovoltaic generator at each climate change and control the motor to achieve it. The system is formed by a boost converter and a three-phase inverter connected to a three-phase LC filter. Numerical management, including the maximum power point algorithm of type "perturbs and observe" to control the boost converter and sinusoidal pulse width modulation of variable frequency to control the inverter is used. The sinusoidal pulse width modulation frequency is given by the PI regulator that compares the motor speed with reference speed. The reference speed is calculated through a program based on climate changes and photovoltaic maximum power. The program is implemented as a Matlab function block. The simulation results show that the PV output voltage and current converge to values corresponding to the maximum power. The motor speed follows the reference speed which approves the good functioning of the PI regulator.

Keywords PV array, boost, maximum power point tracking, inverter, PI regulator, filter, induction motor, pump.

1. Introduction

The regular increase in demand for energy and the depletion of traditional energy sources has led to the use of renewable energies as a complement [1]. Renewable energies are inexhaustible and do not cause environmental damage [2]; making them a better solution to remedy the significant increase in greenhouse gas content in the atmosphere. Regulation and optimization of renewable energy integration in electrical systems are a research axis that arouses great interest considering its contribution to reducing greenhouse gas emissions and its resistance to climate change. Clean, unlimited and widely distributed throughout the globe, solar energy is renewable and presents itself in the earth with a quantity greater than what the world consumes today what makes it plentiful [3].

The exploitation of solar energy for electricity generation is based on photovoltaic cells that trans-form solar radiation into electricity. Photovoltaics module price decreases and the increase of fossil fuel price make the exploitation of photovoltaic power a profitable energy alternative. Photovoltaic energy finds a multiple applications, namely water pumping system [4] [5]. In this context, this work study the regulation of three phase induction motor speed inserted in a solar powered water pumping system for irrigation purpose.

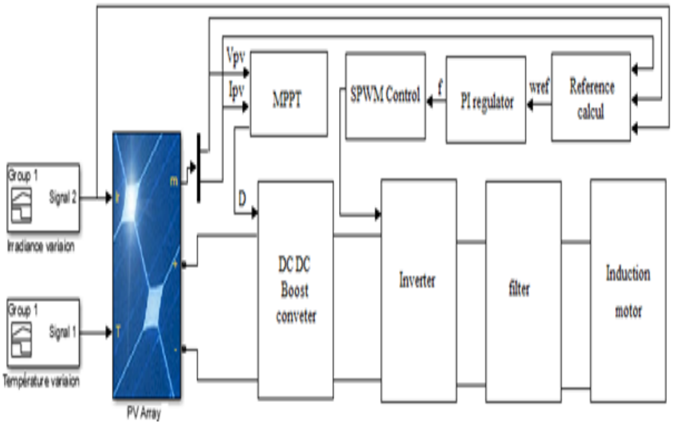

Fig. 1. Block diagram of the sized system.

For better system efficiency, it is advisable to run the motor at a nominal frequency. This frequency depends on the flow rate which is a function of the available electrical power of the photovoltaic generator. Like irradiance and temperature variations affect the water flow. We propose in this study to calculate at any time the reference speed corresponding to the maximum power that can be supplied by the photovoltaic generator and calibrate the motor speed according to the reference. The induction motor conducts a submersible pump and it is supplied through a three phase inverter connected to a three phase LC filter. The inverter fed by the PV array trough DC-DC boost converter. To control inverter switches commutation the sinusoidal pulse width modulation of variable frequency is applied. This frequency is generated by a Proportional Integral regulator that compares the motor speed with reference speed. The reference speed is calculated through a program based on climate changes and photovoltaic maximum power and implemented as a Matlab function block. Converter commutation is controlled by a maximum power point tracking program which is also implemented as a Matlab function block. The whole system is simulated in Matlab, Simulink software by varying temperature and radiation. The system is given in “fig.1.”

1.1 Motor and pump sizing

The submersible multicellular centrifugal pump of power 1070W is used in this system. It is chosen depending on the desired daily water flow and the total depth of the well. This is well described in a previous work [6]. This type of pump can run at very low light and accepts a variable rotational speed which makes it very well suited to photovoltaic pumping systems. Based on the cost and maintenance requirements, the induction motor is better ranked compared to the DC motor for pump drive in photovoltaic applications. In addition, the induction motor offers different control approaches compared to DC motors in such applications [7]. Thus, in this case, a 3-phase induction motor of power 1.09 KW and nominal rotation speed of 2830rpm is used in the pumping chain. A resistive torque proportional to the square of the rotational speed is applied to the motor representing the pump [8].

1.2 PV generator

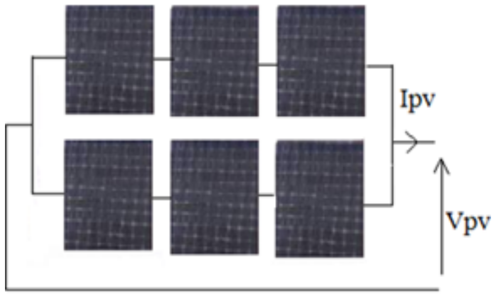

Fig. 2. Connection of solar modules.

The photovoltaic generator is sized to cover the power required for the operation of the asynchronous motor in all climatic conditions. For this purpose the sizing was established based on the actual critical temperature and irradiation conditions of the Beni-Mellal region. Considering these conditions as well as the inverter and the boost converter efficiency that is approximately equal to 0.94 the photovoltaic generator used has a power value of 1.2KW. It is composed of six modules of power 205W each. The voltage required in the panel output is reached by connecting in series three modules of 30V each. The connection of the solar module used is given by “Fig.2”. Photovoltaic generator characteristics are given in “table 1”.

Table 1. Photovoltaic module characteristics

Maximum power	204.9 W
Open circuit voltage Voc	36.4 V
Voltage at maximum power point Vmp	30 V
Temperature coefficient of Voc	-0.3364 %/deg.C
Cells per module	60
Short-circuit current Isc	8.03 A
Current at maximum power point Imp	6.83 A
Temperature coefficient of Isc	0.038468 %/deg.C

The maximum power of the photovoltaic generator changes with the irradiation or temperature variation. To optimize the sizing of the system an adaptation stage is integrated into the pumping chain in order to search for the maximum power of several climatic conditions values and control the system to operate in it.

1.3 DC-DC boost converter

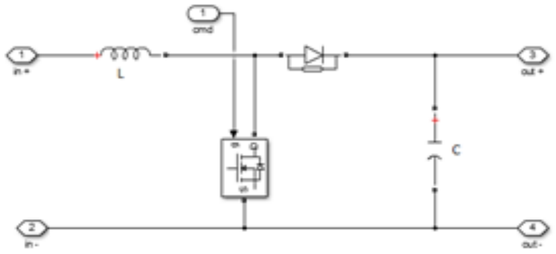

Fig. 3. Boost converter.

The step-up converter performs several functions simultaneously. Since the voltage value that a photovoltaic module can deliver is low. The DC-DC step up converter allows reducing the number of series connected photovoltaic modules. This is done by controlling the converter switch to extract the maximum voltage and current that the photovoltaic generator can produce. “Figure 3” shows the structure of the boost converter [9] [10].

The switching Mosfet control was carried out by the maximum power point tracking control of type "disturb and observe" [11] [12]. It is implemented in Simulink as a program with a Matlab function block. It allows at each climate change to seek the maximum power that corresponds to the values of irradiation and temperature. And control the system to work at that point. Its principle consists of sense the output voltage and current of the photovoltaic generator. Calculate the produced power based on the measurements, and compare it with the reference power value. Increase the duty cycle with a determined step if the calculated power is higher than the reference value or decrease it if not. Replace the reference power value with the calculated power value and repeat these steps until reaching the maximal power that can be supplied by the PV generator. The algorithm of the MPPT is given in “fig.4” [13] [14].

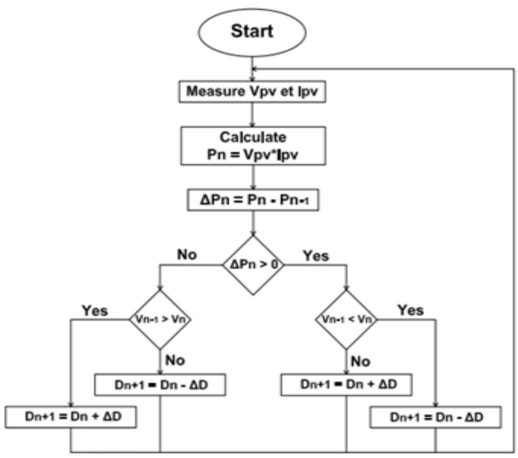

Fig. 4. MPPT algorithm.

The boost converter produces a DC output which requires a stage to make it suitable for the induction motor.

1.4 Inverter and Speed control

The inverter used in our system is a three-phase H-bridge type. It consists of three branches, each branch contains two switches. It generates an alternative voltage output from a continuous voltage input using switching circuits. The inverter is controlled by the sinusoidal pulse width modulation [15] of variable frequency. The concept of this control is to compare a sine reference signal to a high-frequency triangular carrier signal. The sine signal frequency is variable and given by a PI controller. Since our inverter is three-phase, three sine references waves of the same frequency, phase-shifted by 120° are required. It compares the instantaneous magnitude of the sinusoidal signal with that of the triangle signal at a point of time. This results in multiple output pulse of different width per half cycle. This control also regulates the asynchronous motor speed to the maximum value corresponding to the maximum power that supplies the photovoltaic generator. The reference speed is calculated by a program implemented by a Matlab function bloc. It calculates the speed reference depending on the irradiance variation. The MPPT calculate the maximum voltage and current and generates these values to the speed reference calculator program. The program calculates the power transmitted to the pump based on the efficiency and generates the reference speed. The reference speed is compared to the motor speed and given to the PI regulator that produces the corresponding frequency to the SPWM control. The proportional-integral controller has been used because it has a simple structure, high reliability, and good robustness. Its expression is given by “equation (1)”.

$$G(s) = Kp + Ki/s \quad (1)$$

Where Kp is the proportional gain and Ki is the integral gain. The closed loop control is given in “fig.5”

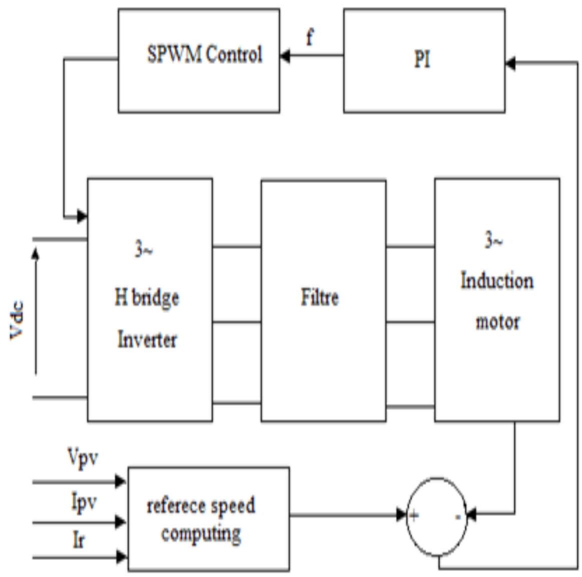

Fig. 5. Induction motor closed loop speed control.

1.5 LC filter

The inverter output signal contains several sinusoidal components and the interrupters switching produce voltage ripple. The induction motor requires a sinusoidal input of attenuated ripple. To get this target a three-phase LC filter is introduced at the inverter output. It eliminates unwanted frequency components and minimizes voltage ripple. Based on the "equation (2)", the inductor and capacitor values were calculated [16].

$$F=2\pi*\sqrt{(LC)} \qquad (2)$$

Where L: is the inductance and C: is the inductance of filter.

2. Simulation results

The pumping chain dimensioned was simulated by varying the irradiation and temperature at the input of the solar panel. The radiation variation is given by the "fig.6". The temperature variation is given by "fig.7". The induction motor model used is given by Simulink software. The motor characteristics used to simulate the pumping chain are taken from a real motor of the required power.

The irradiation curve starts at the value of 1000W/m2. At the time 25s the curve gets down and arrives at the value 500w/m2 in the 30s.

The temperature curve starts at the value of 25°C. At the time 25s the curve falls and get to 6.4°C in the 30s.

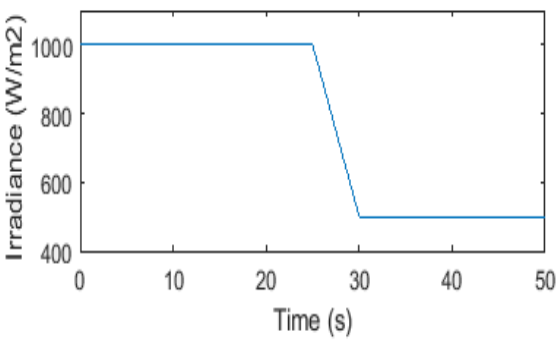

Fig. 6. Irradiance curve.

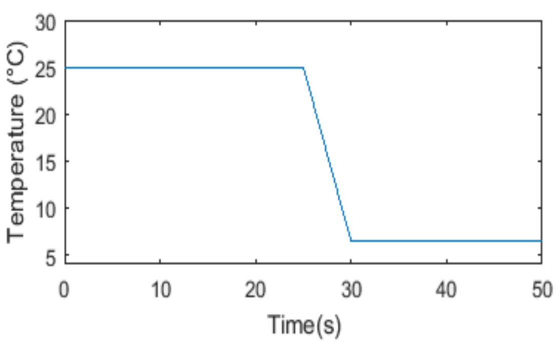

Fig. 7. Temperature curve.

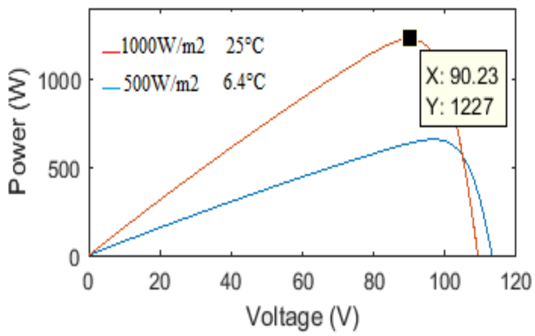

Fig. 8. Photovoltaic generator P-V characteristics.

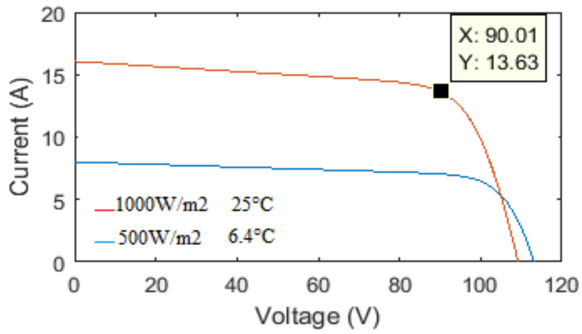

Fig. 9. Photovoltaic generator V-I characteristics.

The photovoltaic array sized is simulated in Simulink under the climatic conditions applied to the system. The resulted P-V and V-I curves of the photovoltaic generator are given in "fig.8" and "fig.9".

The photovoltaic generator used presents a maximum power of 1.2KW under 1000W/m2 and 25°C. The decrease of irradiance and temperature values results in a degradation of the power to 643.3W.

The maximum photovoltaic current and voltage that could be generated under the radiation 1000W/m2 and temperature 25°C are 90.652V and 13.5A. Whereas the maximum values of current and voltage that the PV generator can supply under 6.4°C and 500W/m2 are 90.92V and 7A.

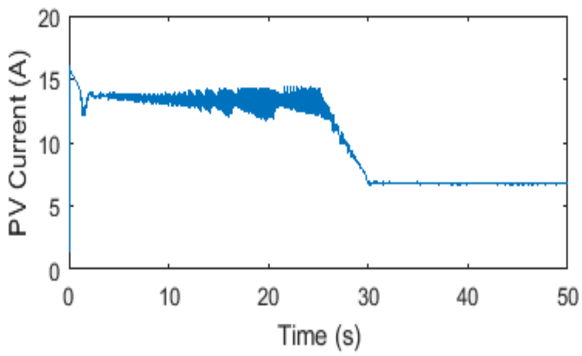

Fig. 10. Photovoltaic output current.

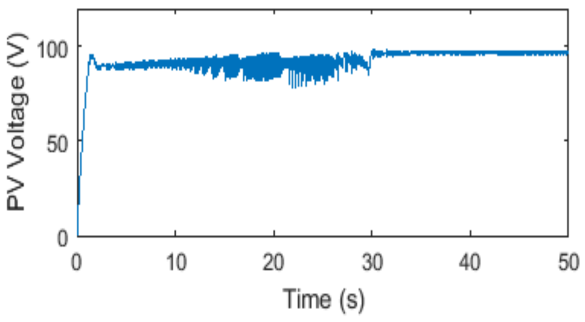

Fig. 11. Photovoltaic output voltage.

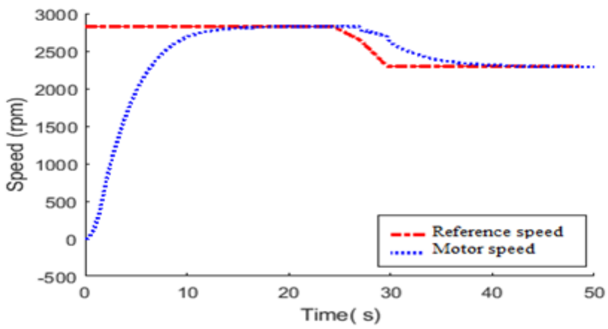

Fig. 14. Speed response and reference speed.

The output current of the solar panels is given in “fig.10”. It reaches the maximum value corresponding to radiation 1000W/m2 and temperature 25 °C. The variation of radiation imposes the variation of the current curve. The maximum power point program controls the current to reach the new maximum value corresponding to radiation 500W/m2 and temperature 6.4°C at the moment when irradiation stabilizes.

The output voltage of the solar panels is given in “fig.11”. It varies with the variation of the irradiation. The sinusoidal pulse width modulation controls the voltage also to reach the corresponding maximum value. The MPPT adapter is efficient for extracting maximum power which helps to exploit the optimum speed and obtain maximum water flow.

The PI regulator output is given in “fig.12”. It starts initially by generating a low frequency and calibrate it according to the amount of energy available from the solar generator. It stabilizes at a frequency of 47.7 Hz at the beginning where the radiation and temperature values are optimal. The drop of irradiance and temperature values decrease the power supplied by the PV generator. The PI regulator changes the generated frequency value to 41.61 Hz to get the new maximum speed value.

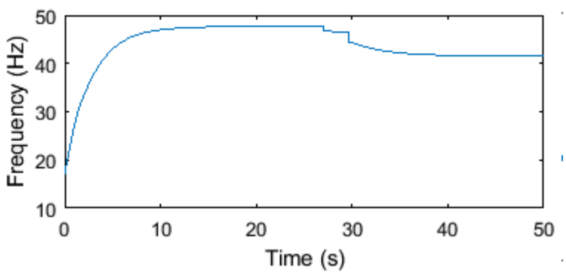

Fig. 12. Sinusoidal pulse width modulation frequency.

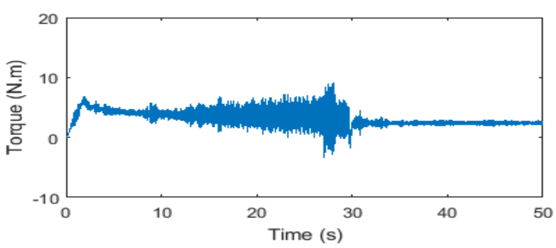

Fig. 13. Asynchronous motor torque.

The torque curve is given in “fig.13”. It oscillates around the nominal value when the irradiation and temperature values are optimal. The drop in radiation and temperature curves affects the torque which falls from its nominal value.

The motor speed and speed reference curves are given in “fig.14”. The motor speed starts initially slowly and follows the reference speed in both cases of climatic conditions. There is no overflow. The PI regulator is efficient for controlling the motor speed to reach the reference speed.

3. Conclusion:

This work has been directed towards the regulation of three-phase induction motor speed used in a solar-powered water pumping system for irrigation purposes. We have presented our contribution to such important scientific point of view field by focusing on the water flow regulation of a pump driven by an asynchronous machine. This is done by controlling the SPWM frequency. This modulation controls the three phase inverter switches commutation. The inverter is introduced between the DC-DC boost converter and the pump. The photovoltaic generator has different V-I curves for different climatic conditions. The maximum power point tracking control "disturb and observe" has been programmed to control the step-up converter, which allows the system to operate at the maximum power point of the photovoltaic generator. A block that calculates the reference speed according to the PV maximum power is implemented. To simulate the performance of the system, radiation and temperature variations were applied. The simulation results show that the MPPT adapter is efficient for extracting maximum power that can be supplied by the PV generator. The motor speed follows the reference speed which approves the efficiency of the PI regulator. The technique used presents oscillations of the torque during climatic variations, these oscillations can be reduced by setting the regulator used by more precise methods or even by the use of another more effective control strategy.

References

[1] A. Harrag, A. Titraoui, H. Bahri, and S. Messalti, “Photovoltaic pumping system - Comparative study analysis between direct and indirect coupling mode”, AIP Conference Proceedings, Vol. 1814, No. 1, pp. 020002, AIP Publishing, February .2017.

[2] S. S. Chandel, M. N. Naik, R. " Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies", Renewable and Sustainable Energy Reviews, Vol. 49, pp.1084-1099, 2015.

[3] T. A. Binshad, K. Vijayakumar, M. Kaleeswari, " PV based water pumping system for agricultural irrigation", frontiers in Energy, Vol. 10, No. 3, pp. 319-328, 2016.

[4] M. I. Chergui, and M. O. Benaissa, "Strategy photovoltaic pumping system in scattered area", IEEE International Conference on Renewable Energy Research and Applications (ICRERA), pp. 283-286, November 2015.

[5] O. M. Akeyo, V. Rallabandi, and D. M. Ionel, "Multi-MW solar PV pumping system with capacity modulation and battery voltage support", IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), pp. 423-428, IEEE, November 2017.

[6] G. Chbirik, A. Abdelouahed, and Z. Massaq, "Contribution to the improvement of a solar pumping system based on asynchronous machine", International Conference of Computer Science and Renewable Energies (ICCSRE), IEEE, pp. 1-5, 2019.

[7] V.C. Sontak, and V. R. Kalamkar. "Solar photovoltaic water pumping system-A comprehensive review", Renewable and Sustainable Energy Reviews, Vol. 59, pp. 1038-1067, 2016.

[8] A. Khiareddine, C. B. Salah, and M. F. Mimouni, " Control water level of a photovoltaic pumping system", Control, Decision and Information Technologies (CoDIT), International Conference on IEEE, pp. 435-440, May 2013.

[9] V. SINGH, and A. N. TIWARI, "Study and Comparison of various types of Converters used for Solar PV: A Review", In: 2018 International Conference on Power Energy, Environment and Intelligent Control (PEEIC), IEEE, pp. 658-664, 2018.

[10] K. Basaran, and N. S. Cetin, "Designing of a fuzzy controller for grid connected photovoltaic system's converter and comparing with PI controller", IEEE International Conference on Renewable Energy Research and Applications (ICRERA), pp. 102-106, November 2016.

[11] D. SERA, L. MATHE, T. KEREKES, and R. Teodorescu, "On the perturb-and-observe and incremental conductance MPPT methods for PV systems", IEEE journal of photovoltaics, Vol. 3, No.3, pp. 1070-1078, 2013.

[12] M.A. ABDOURRZIQ, M. OUASSAID, and M. MAAROUFI, "Single-sensor based MPPT for photovoltaic systems", International Journal of Renewable Energy Research (IJRER), Vol. 6, No. 2, pp. 570-579, 2016.

[13] D. Foito, A. Cordeiro, T. Amaral, and V. F. Pires, "A Water Pumping Photovoltaic Powered System Based on a DC-DC Converter with Dual Output and Extended Voltage Gain", 8th International Conference on Renewable Energy Research and Applications (ICRERA), IEEE, pp. 206-211, November 2019.

[14] B. Veerasamy, A. R. Thelkar, G. Ramu, and T. Takeshita, "Efficient MPPT control for fast irradiation changes and partial shading conditions on PV systems", IEEE International Conference on Renewable Energy Research and Applications (ICRERA), pp. 358-363, November 2016.

[15] S. Phogat, "Analysis of single-phase SPWM inverter", International Journal of Science and Research, Vol. 3, No.8, pp. 1793-1798, 2014.

[16] M. D. Patil and R. G. Ramteke "LC filter design implementation and comparative study with various PWM techniques for DCMLI", International Conference on Energy Systems and Applications, IEEE, pp. 347-352, 2015.