Optimization of PV output for Centrifugal Pumping System Operated by Induction Motor

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ABSTRACT
Renewable energy sources are the most prominent Energy Sources, it has many advantages over the Conventional Energy Sources. PV Technology is most Promising technology, it is increasingly being employed as a replacement of Conventional Energy Sources. In this paper the Model is developed by Using Photovoltaic Panels, Boost Converter which Converts DC to DC Voltage that Steps Up the Voltage produced by the PV Array to a value, which is suitable to run a three phase Induction Motor and Induction Motor is Directly Coupled with Centrifugal Pump. The Inverter Converts DC to AC Voltage, controlled by using Pulse Width Modulation (PWM) Technique. An LC Filter is used to eliminate harmonics and Induction Motor and Centrifugal Pump is presented. The model is implemented using MATLAB/Simulink .

Keywords : Photovoltaic generator (PV), Maximum power point tracking (MPPT), DC/DC converters, Induction motor, Pulse Width Modulation(PWM),Indirect torque control, Centrifugal Pump.

INTRODUCTION

Solar energy is the most low cost, competition free, universal source of energy as sun shines throughout. This energy can be converted into useful electrical energy using photovoltaic technology. The steady state reduction of price per peak watt and simplicity with which the installed power can be increased by adding panels are attractive features of PV technology. Among the many applications of PV energy, pumping is the most promising. In a PV pump storage system, solar energy is stored, when sunlight is available as potential energy in water reservoir and consumed according to demand. There are advantages in avoiding the use of large banks of lead acid batteries, which are heavy and expensive and have one fifth of the lifetime of a PV panel. A number of experimental DC motor driven PV pumps are already in use in several parts of the world, but they suffer from maintenance problems due to the presence of the Commutator and brushes. Hence a pumping system based on an induction motor can be an attractive proposal where reliability and maintenance-free operations with less cost are important. The effective operation of Induction motor is based on the choice of suitable converter-inverter system that is fed to Induction Motor. Converters like Buck, Boost and Buck-Boost converters are popularly used for photovoltaic systems. The Induction Motors are the AC motors and hence from converter, an inverter system is also required to obtain an AC voltage. This inverter is chosen based on its advantages and it is fed to induction motor.

Photovoltaic panels require specific control techniques to ensure operation at their maximum power point tracking (MPPT).

A typical configuration of a photovoltaic pumping system is shown in Fig. 1. The system comprises the following components: 1) photovoltaic panels; 2) dc/dc converter; 3) dc/ac inverter 4) induction motor and 5) centrifugal pump.

In addition to its voltage-boosting function, required for load matching, the dc/dc converter implements MPPT for the photovoltaic array. There are Several MPPT methods. Some consider specific conditions, such as partial shadowing or fast insolation change. For the sake of simplicity, the MPPT used in this paper is based on the incremental conductance algorithm.

Currently, the induction motor is more and more used in photovoltaic pumping systems. This kind of motors has been adopted due to its low cost and the low maintenance requirements. In addition, the increased efficiency of solar pumping systems makes this latter particularly attractive, even more the additional cost of the inverter is less significant. In recent years, the advent of efficient inverter to control the speed of these motors has allowed their use for solar pumping applications.

Photovoltaic Pumping System: Fig. 1 shows the proposed structure of the photovoltaic pumping system.

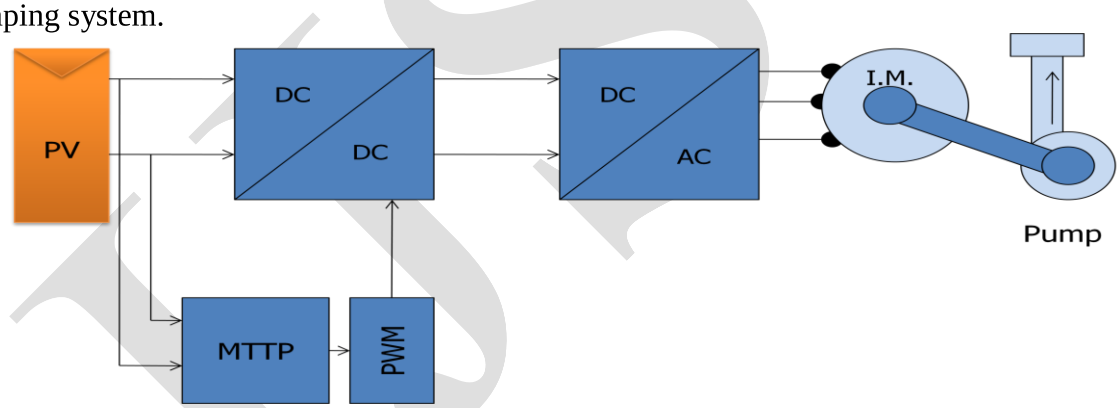

Figure. 1 Structure of the photovoltaic pumping system

The proposed model consists of several modules as shown in **Figure 1** with the following functions:

PV Photovoltaic Array (*PV*) that converts the solar irradiation into voltage *Vpv* and current *Ipv*.

Buck-Boost DC Chopper Module that boosts up the PV voltage to the predetermined levels. Conversely in case of high *Vpv* the output voltage is reduced.

MPPT, maximum power point tracking unit that tracks the optimized operation point for power extraction by controlling the chopper duty cycle.

Inverter, which convert DC to AC voltage for running the Induction motor at suitable speed.

Centrifugal Pump, directly coupled with the Induction Motor and give required output.

The rest of the paper is organized as follows. Modeling of proposed electrical model such as Photovoltaic Model Interpretation, Centrifugal Pump Model, and SIMULINK Model of

Proposed Pumping System are explained in section II.Concluding remarks are given in section III.

MATERIALS AND METHODS

Modeling of proposed electrical model

A. **Mathematical Modeling of PV Panels**

***A*.a) Photovoltaic Model Interpretation –**

Basically, PV cell is a P-N semiconductor junction that directly converts light energy into electricity. It has the Equivalent circuit shown in Figure 2.

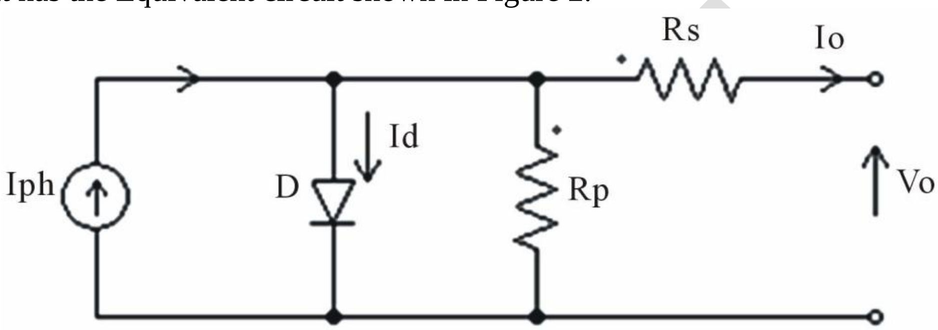

Figure 2.Eqivalent Circuit for PV Cell

Mathematical Modeling of PV Panels

- Tr is the reference temperature = 298 K
- T is the module operating temperature in Kelvin
- Iph is the light generated current in a PV module (A)
- Io is the PV module saturation current (A)
- A = B is an ideality factor = 1.3
- k is Boltzman constant = 1.3805 × 10-23 J/K
- q is Electron charge = 1.6 × 10-19 C
- Rs is the series resistance of a PV module Rs=.18ohm
- Iscr is the PV module short-circuit current at 25°C and Irradiation1000W/m2 = 5A
- Rp is the Parallel resistance of a PV module Rp=780ohm
- Voc is the PV module short-circuit current at 25°C and Irradiation1000W/m2 =230V

The Following are the simplified equations describing the cell output voltage and current:

$$Vo = \frac{A.K.TC}{q} In[\frac{(Iph + Id - Io)}{Io}] - Rs.Io$$

$$Io = Np\left[Iph - Id(e^{\frac{q.Vo/Ns}{A.K.Tc}} - 1)\right]$$

$$Id = Ior\left(\frac{Tc}{Tr}\right)^3 . e^{\frac{q.Eg}{B.K}}\left(\frac{1}{Tr} - \frac{1}{Tc}\right)$$

$$Iph = Np.\{Isc.\emptyset + It(Tc - Tr)\}; \emptyset n = G/Gr$$

The following are the simplified equations describing the cell output voltage and current: The idealistic diode idealistic factors A & B are with values vary between 1 and 2 depending on I-V performance shaping and approximations.

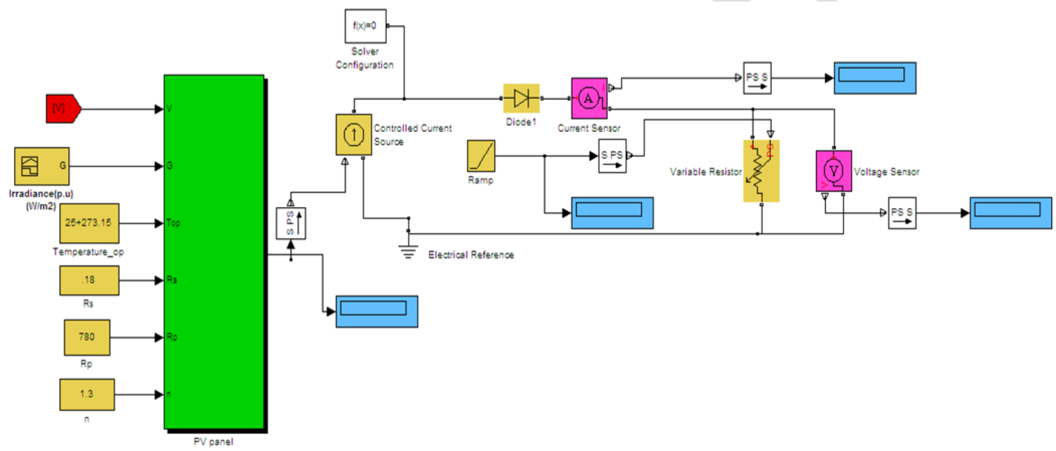

Figure 3.Matlab/Simulink Model of Solar Panal

A.b) Photovoltaic I-V Performance –

In order to study the I-V performance of the PV circuit and to look for appropriate dc chopper for boosting up the output voltage to predetermined value it is necessary to illustrate the obtained PV voltage and current for boost chopper Figure 4 and Figure 5 illustrates the proposed PV array built in Matlab/Simulink. where the obtained results for different variation levels are presented. From these performances it is shown that the total output PV voltage and current varies according to irradiation level with approximated 900W maximum power at G = 900 W/m^2.

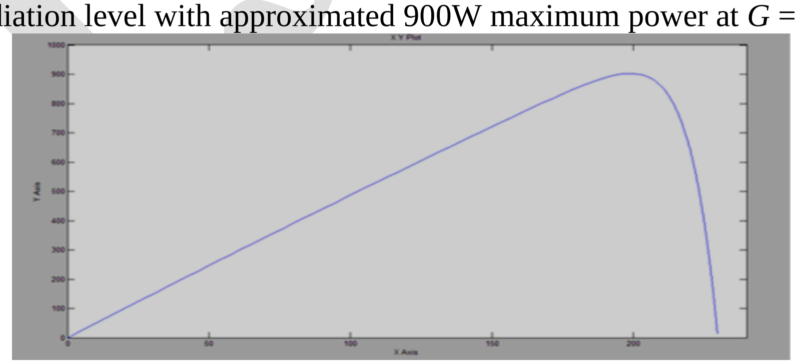

Figure 4 P-V Curve

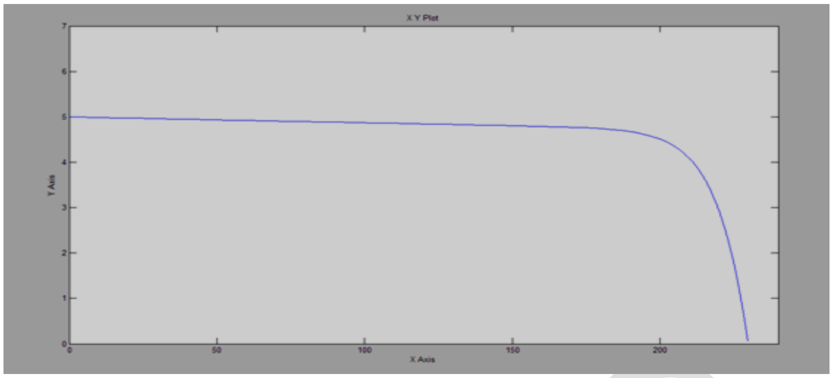

Figure 5 I-V Curve

A. c) MPPT Based On DC-DC Boost Converter-

To extract, at each moment, the maximum power available at the terminals of the PV and transfer this latter to the load, the technique conventionally used is to achieve an adaptation stage between the PV and the load. This stage plays the role of an interface between the two elements ensuring throughout control process, the transfer of the maximum power supplied by the generator to make it as close as possible to Pmax. DC-DC converters, as voltages elevators, are also used in photovoltaic applications, especially in photovoltaic pumping system. In our study we use a boost converter which is a power converter with an output voltage greater than its input voltage. The MPPT control acts on the duty cycle of the converter as so that the power supplied by the PV will be equal to Pmax provided at its terminals. The MPPT algorithm can be more or less complicated to find the Maximum Power Point MPP, but generally it is based on the variation of the duty cycle of the converter to be putted on the MPP: in terms of changes in input parameters converter (IPV and VPV) .

B. Mathematical Modeling of Boost Converter

Converter is used to convert unregulated supply in to regulated supply.
The average output voltage is controlled by switching on and off time duration.
At constant frequency adjusting the on and off duration of the switch is called PWM switching.
There are basically two modes:
1. Discontinuous Mode
2. Continuous Mode
In this project converter is working in Continuous Conduction Mode , Consider :
1) Current Ripple Factor(CRF):
According to IEC harmonic Standard , CRP should be bounded with in 30%
$\Delta IL/IL=30\%$
2) Voltage Ripple Factor(VRF):
Voltsage Ripple Factor = $\Delta Vo/ Vo =5\%$
3) Switching Frequency(fs):
fs=100kHz

C. Mathematical Modeling of Inverter

PWM Inverter is designed using IGBT. Gating signal is provided by comparing the actual stator currents and reference stator currents.
Input Voltage=300V
The output of inverter is passed through outage and then Low Pass filter to get sinusoidal wave on Va, Vb and Vc.

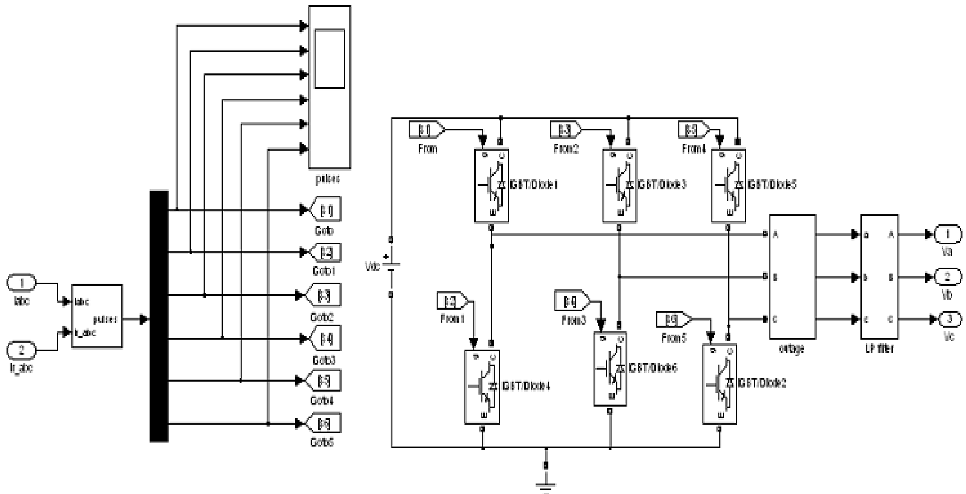

Figure 6.Matlab/Simulink Model of Inverter

D. Mathematical Modeling of Induction Motor

Indirect Torque Control of the Induction Motor –

An induction motor drive includes several components in addition to the machine itself. These include the power electronics inverter, controller and associated sensors. Two current sensors give the phase current feedback to the controller, and a speed encoder provides the rotor angular position. The controller processes the sensor feedbacks and controls the inverter for desired operation. The control algorithm can be torque control or speed control. In this paper, the focus will be on speed control with inner-loop current control. The speed control method allows direct speed control as well as indirect torque control. In this case, machine actual speed is compared with the reference speed to generate the reference current, which is compared with the actual current to generate the duty cycles for PWM signals.

There are two general methods of vector control. One is called the direct method, for which air gap flux is measured directly. A flux sensor is necessary for the direct method of vector control. Another method is known as indirect method of vector control; this method eliminates the measurement of air gap flux but requires knowledge of the angular position of the rotor. Therefore, a speed sensor is required to estimate the rotor angle.

D.a) Mathematical Modeling of Vector Controller

- Reference Torque (Te*) and Controlled Rotor Flux (Yr) is fed as input to Vector Controller.
- Following equations are implemented to get the reference stator current (is*) and slip angular frequency (wsl).

The equations are:

$Iq^* = (4.\ Lr.\ Te^*)/(3.\ P.\ Lm)$

$I_d^* = Yr / Lm$

$Is^* = \text{sqrt}\ [(id^*)^2 + (iq^*)^2]$

Wsl = Rr / (Lr. id^*)

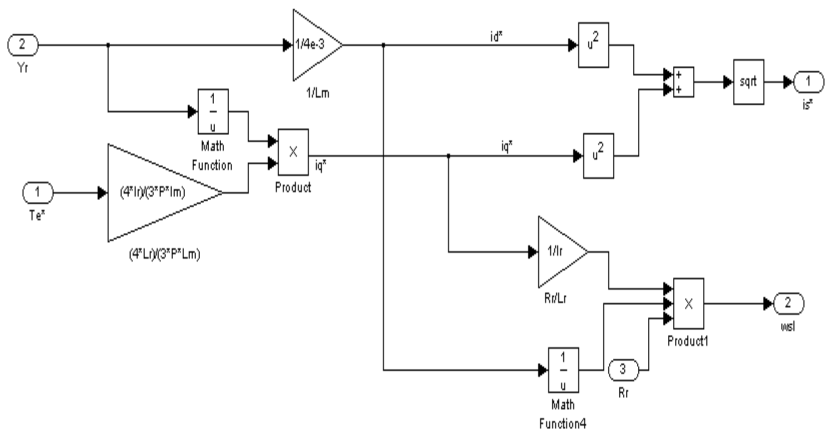

Figure 7.Matlab/Simulink Model of Vector Controller

D.b) Mathematical Modeling of Stator Current

The reference stator current is reconstructed using the angular position theta(Q) and reference stator current(Is*) using the relations given below:

Iref_a = Is* cosQ

Iref_b = Is* cos (Q – 2*pi/3)

Iref_c = Is* cos (Q + 2*pi/3)

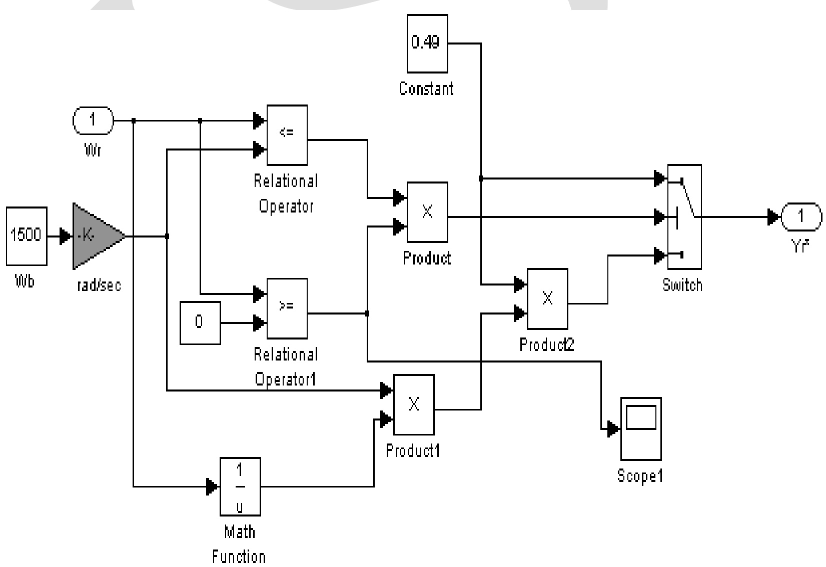

Figure 7.Matlab/Simulink Model of Stator Current

The reference flux (Yr*) is generated using above simulation. The reference speed is compared with actual rotor speed (Wr) .If the rotor speed is lesser than the reference but greater then zero then the reference flux 0.49 is selected else (0.49*Wref)/Wb is selected. Hence the flux is controlled with respect to rotor speed.

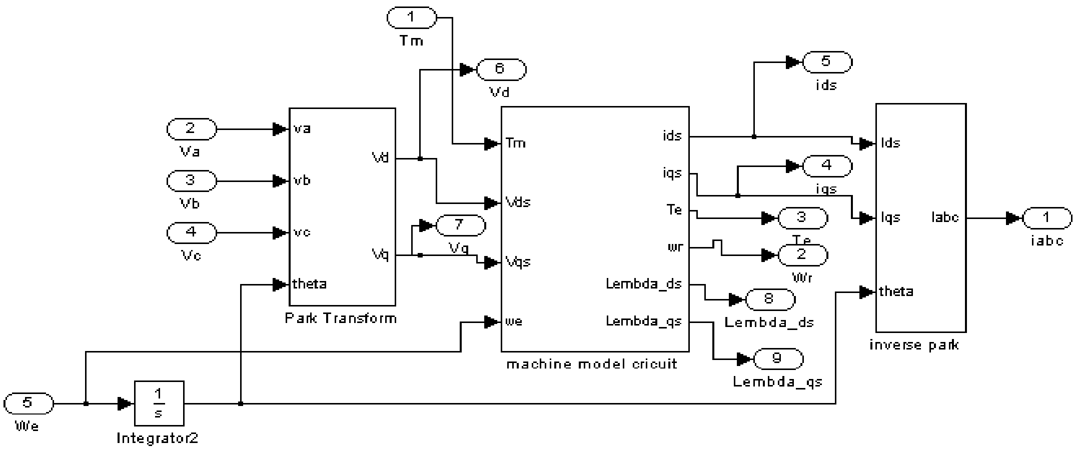

Figure 8: Induction motor drive structure with indirect vector controller.

E. Mathematical Modeling of Centrifugal Pump

The flow-head characteristic of a centrifugal pump can be approximated by quadratic form using these Equation and can be expressed approximately by the following form

Where: N=Speed =1510rpm

D_2=Diameter = .127 meter

H = Net Head =10meter

Ƞ = Manometric Efficiency =50%

Vw_2 = Outlet Velocity

H=Net Head=10m

B_2=Width of the outlet=.2365meter

$$u_2 = \pi . D_2 . N/60$$

$$\eta_{man} = \frac{gHm}{Vw2.u2}$$

$$\tan \emptyset = \frac{Vf2}{(u2 - Vw2)}$$

$$Q = \pi . D2 . B2 . Vf2$$

Simulation and Results:

SIMULINK Model of Proposed Pumping System –

A Matlab/Simulink for proposed mathematical model is presented for induction motor pump, taking into account that varying the motor voltage and frequency in accordance with water flow-rate level saves energy and operates the motor at maximum pump efficiency. **Figure 9** presents the whole Simulink model including solar PV model, Variable voltage-variable frequency inverter system, Pump system, and water flow-rate system, that predicts the water flow-rate and regulates both voltage and frequency by using the variable voltage variable frequency (VFD) technology in order to keep the motor operating at constant torque.

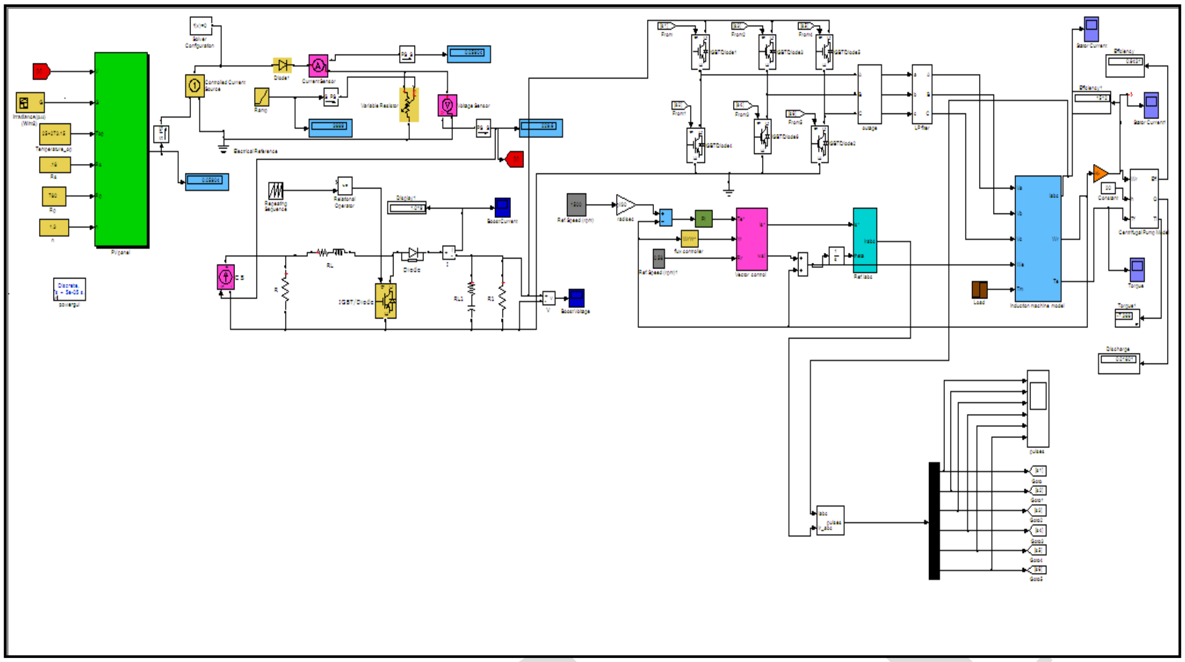

Figure 9. Matlab/Simulink model of Induction-motor Pump.

The following figures show the simulation results of the photovoltaic system studied for 0.9 kW/m2 irradiance and a temperature of 25°C.

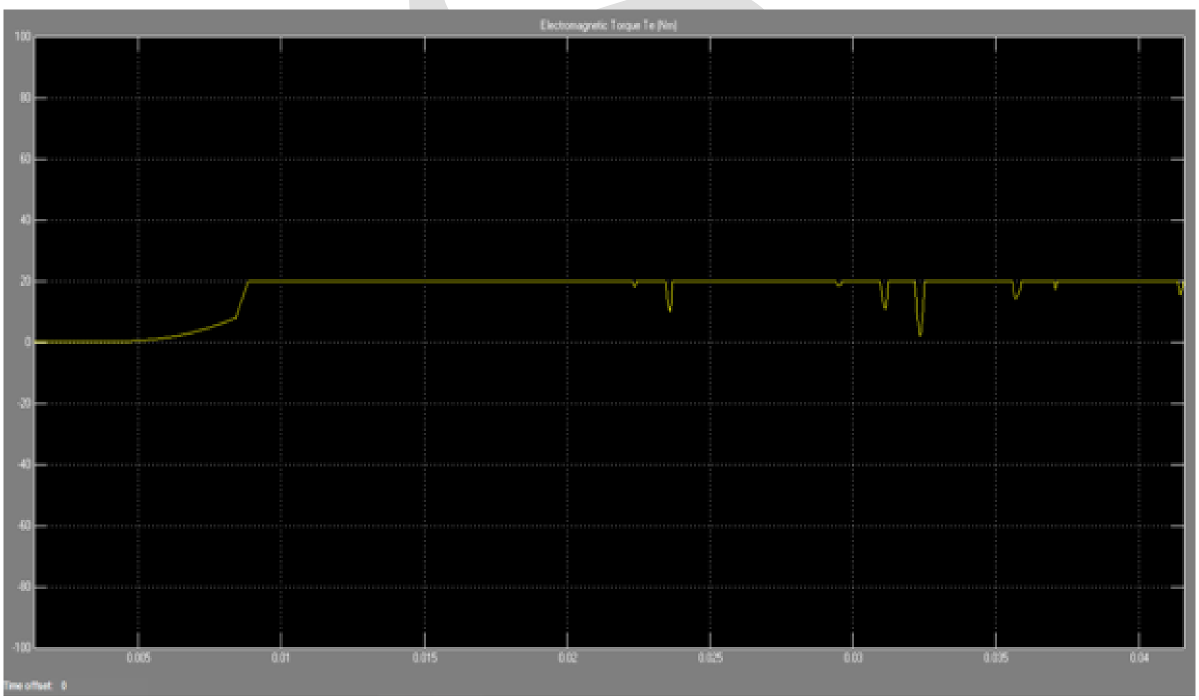

Figure 10.The Electromagnetic Torque

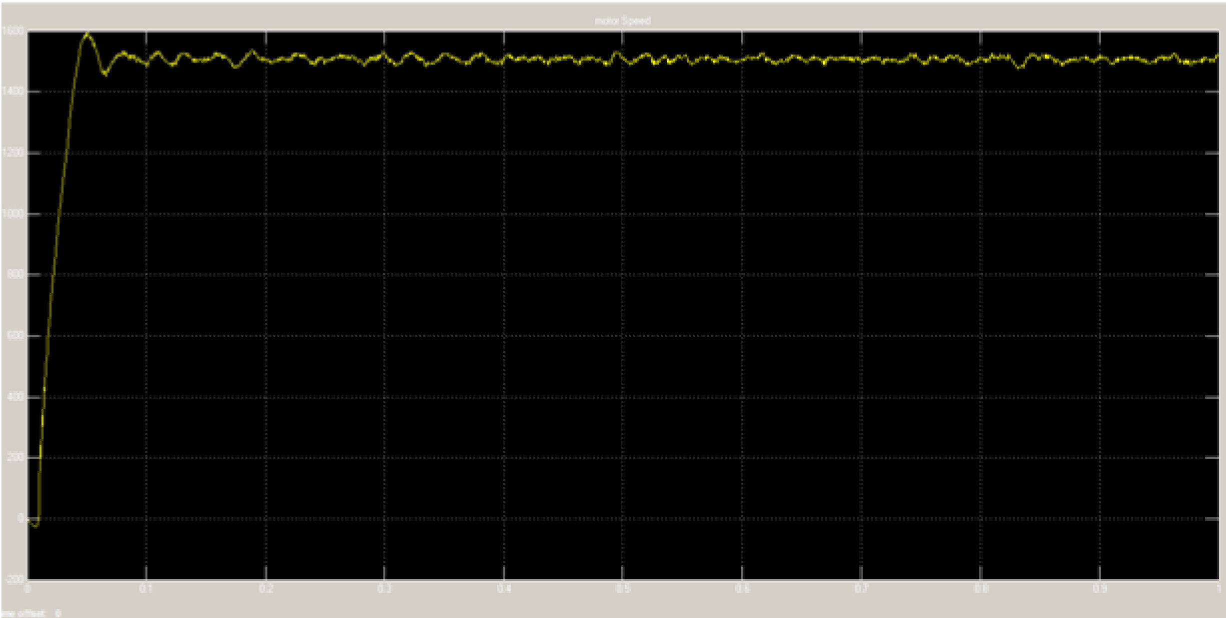

Figure 11.The Speed

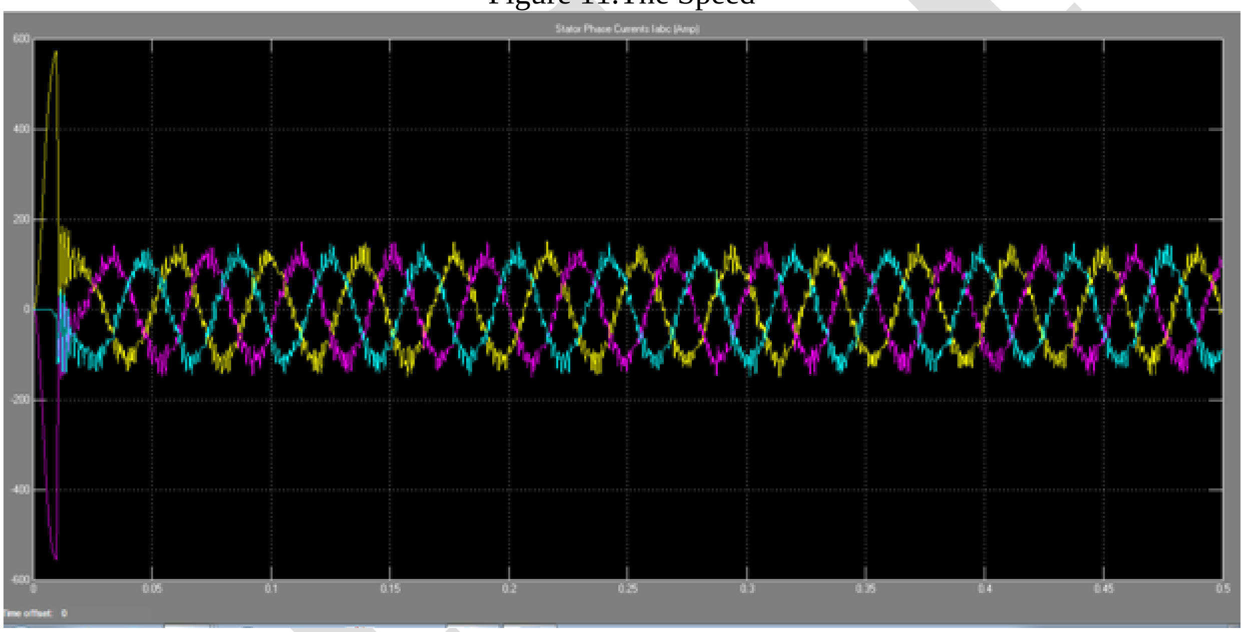

Figure12.Stator Current

CONCLUSION

This Project has evaluated a effective control structure using-

1. The concept of Vector Control method for induction motor
2. The operation at MPPT for the DC-DC converter.

The strategy of Vector Control served here as a way to control the flow of the pumping station. The command with the adapter MPPT optimizes power delivered by the photovoltaic generator according to the irradiance and the temperature. This allowed the station to operate at the optimal operating point. Simulation results are satisfactory. Indeed, the motor speed tracks the value of the reference speed desired and consequently the value of the desired pump flow.

REFERENCE

[1] Montiê Alves Vitorino, Maurício Beltrão de Rossiter Corrêa, Member, IEEE, Cursino Brandão Jacobina, Senior Member, IEEE, and Antonio Marcus Nogueira Lima, Senior Member, IEEE "An Effective Induction Motor Control for Photovoltaic Pumping", IEEE, April 2011, ISBN: 0278-0046, Val. No.:58, Page No.4,

[2] R. Gules, J. D. P. Pacheco, H. L. Hey, and J. Imhoff, "A maximum power point tracking system with parallel connection for PV stand-alone applications," IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2674–2683, Jul. 2008.

[3] N. Femia, G. Lisi, G. Petrone, G. Spagnuolo, and M. Vitelli, "Distributed maximum power point tracking of photovoltaic arrays: Novel approach and system analysis," IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2610– 2621, Jul. 2008

[4] H. Patel and V. Agarwal, "Maximum power point tracking scheme for PV systems operating under partially shaded conditions," IEEE Trans. Ind. Electron., vol. 55, no. 4, pp. 1689–1698, Apr. 2008

[5] D. Kirschen, D. Novotny, and T. Lipo, "On-line efficiency optimization of a variable frequency induction motor drive," IEEE Trans. Ind. Appl., vol. IA-21, no. 3, pp. 610–616, May/Jun. 1985.

[6] D. Sera, R. Teodorescu, J. Hantschel, and M. Knoll, "Optimized maximum power point tracker for fast changing environmental conditions," in Proc. IEEE ISIE, 2008, pp. 2401–2407.

[7] E. Muljadi, "PV water pumping with a peak-power tracker using a simple six-step square-wave inverter," IEEE Trans. Ind. Appl., vol. 33, no. 3, pp. 714–721, May/Jun. 1997.

[8] J. Arribas and C. González, "Optimal vector control of pumping and ventilation induction motor drives," IEEE Trans. Ind. Electron., vol. 49, no. 4, pp. 889–895, Aug. 2002.

[9] M. A. Vitorino, M. B. R. Correa, C. B. Jacobina, and A. M. N. Lima, "Sensorless induction motor drive for photovoltaic pumping applications," in Proc. IEEE APEC, Feb. 2008, pp. 1139–1143.

[10] K. B. Rohit[1], Prof. G. M. Karve[2], Prof. Khatri[3] "Solar Water Pumping System" IJETAE Trans. Ind. Electron., vol. 3, no. 7, pp. 2250–2459, Jul. 2013.

[11] K. Vijaya Bhaskar Reddy[1] and G.V. Siva Krishna Rao[2] "Experimental Results of Photovoltaic Powered Induction Motor Drive for Pumping" IJEEE Trans. Ind. Electron., vol. 7, no. 3, pp. 247–254, Jul. 2014.