Operation of a 3-Phase Induction Motor Drive Fed by a PV Cell in Conjunction with Closed Loop Boost Converter

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ABSTRACT

This paper presents a photovoltaic array (PVA) simulation model to be used in Matlab-Simulink GUI environment. The model is developed using basic circuit equations of the photovoltaic (PV) solar cells including the effects of temperature changes and solar irradiation. This PVA model is used with boost converter to analyze its output and usage for various constant DC operations efficiently. Further an applications of solar panel of low output voltage is shown in which the panel is simulated with boost converter and then its output is given to an SVPWM fed inverter which provides 3 phase AC supply for 3 phase induction motor, which is feeding half of the industrial world. The advantage of using PID controller with closed loop converters is also shown in this paper, which provides constant DC. The simulation of closed loop converter with solar panel is done and the results are presented.

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Introduction

Today people are finding the benefits of having their own renewable energy system more attractive than they ever had before. Specially, energy from the sun is the best option for electricity generation as it is available everywhere and is free to harness. The merits of solar PV system are cleanness, relative lack of noise or movement, as well as their ease of installation and integration when compared to others. In practical applications, PV arrays can be used in battery charging, water pumping, PV vehicles, satellite power systems, grid-connected power systems, standalone power systems, and so on. A steady-state analysis employing direct coupling between a series dc motor, shunt dc motor or separately excited dc motors and the PV solar arrays has been given by Roger [1].

The starting and steady-state characteristics of dc motors powered by a solar cell array source have been studied by Appelbaum [2]. All these studies concerning dc motors or permanent magnet (PM) dc motors powered by PV generators have been done by considering the direct interface between the motor load and the PV source generator. For direct coupling of dc motors to PV solar arrays, the separately excited or PM motors with a ventilator type load are the most suitable [2], but the cost of PV system is of great concern.

Due to the low conversion efficiency of PV arrays, one way to reduce the cost of the overall system is by using high efficiency power processors. The power processor usually adopts a DC/DC converter as its energy processing system .The solar energy conversion system provides the complete utilization of the solar energy impinging on solar collectors by having cylindrical lens type collection panels. The PV combiner box is necessary to combine many wires into a few wires. The DC-DC converter converts a DC input voltage, to a DC output voltage, with a magnitude lower or higher than the input voltage.

DC-DC converters are considered to be of great economic importance in today's society, and are perhaps one of the few electronic circuits that are commonly used in switching power supplies, generally are widely used at home solar systems to produce the desired output power .In this paper solar panel with boost converter is simulated, also when there is variation in solar panel output voltage, closed loop control using PID controller is used with boost converters so that a controlled or constant DC output voltage is obtained at its output, which can be efficiently used for constant DC loads, whether it be battery chargers, DC drives or AC drives with the help of inverters.

An induction motor is used at the output of high output boost converter with the help of a 3 phase bridge inverter which converts DC output voltage of boost converter into 3 phase AC voltage and then the output is given at the 3 phase induction motor, which is a very useful motor now a days. The analysis of speed variation of 3 phase induction motor is also done and its effects on other parameters such as stator current, rotor current and torque is analyzed.

Characteristics of PV Cell

An ideal PV cell is modeled in Figure 1 by using a current source in parallel with a diode, but no cell is ideal and therefore series and shunt resistances are added to the model [3]. RS is the intrinsic series resistance with very small valve and. RP is the equivalent shunt with very high valve. [4]
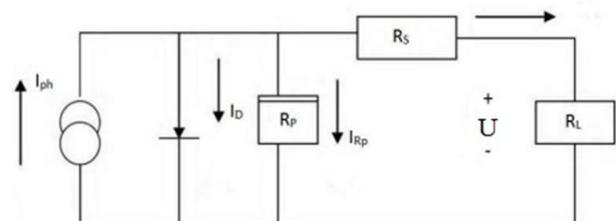
Figure 1. PV Cell

Applying Kirchhoff's law at node where R_S, R_P, I_{ph} meets is given by:

$$I_{ph} = I_D + I_{R_p} + I \tag{1}$$

$$I = I_{ph} - \left[e^{\frac{(U+IR_s)}{U_t}} - 1 \right] - \left[\frac{(U + IR_s)}{R_p} \right] \tag{2}$$

Here
I_{ph} is the Insolation current,
I is the Cell current,
I_D is the Reverse saturation current,
U is the Cell voltage,
R_S is the Series resistance,
R_P is the Parallel resistance,
U_t is the Thermal voltage (KT/Q),
K is the Boltzmann constant,
T is the Temperature in Kelvin,
q is the Charge of an electron.

PVA Modelling

PV arrays can be made with the combination of series and parallel PV solar cells, which can be represented with the help of following equivalent model, shown in figure 2.
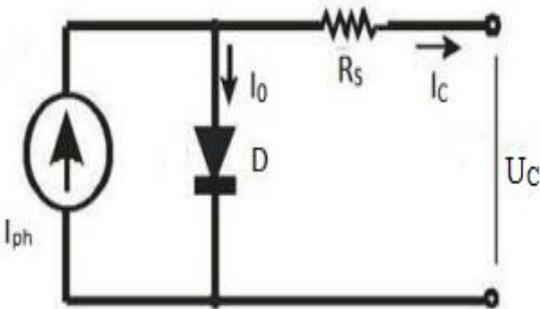
Figure 2. Equivalent model of PV cell

$$U_C = \frac{AKT_C}{e} \ln\left(\frac{I_{ph}+I_0-I_C}{I_0}\right) - R_S I_S \qquad (3)$$

Here,
e=charge of electron i.e. $1.602*10-19$ C
K = Boltzmann constant i.e. $1.38×10-23J/K$
I_{ph} = Photocurrent i.e. function of irradiation level and junction temperature (5 A)
I_C = Cell output current
I_0 = Reverse saturation current of diode i.e. 0.0002 A
R_S = series resistance of cell i.e. 0.001 Ω
T_C = reference cell operating temperature i.e. 20 °C
U_C = cell output voltage
K and T_C both temperatures have the same unit of either kelvin or Celsius.

A is the curve fitting factor and it helps to adjust the current-voltage characteristics of the PV cell obtained from Eqn. (3) to the actual characteristics which is obtained by testing. The above given Eqn. (3) gives the actual voltage of one solar cell and then it can be multiplied by total cells connected in series of an array to calculate the total voltage of array.

As the sum of current flowing through the cells connected in parallel branches is the array current, the cell current I_C is obtained by dividing the array current by the no. of cells connected in parallel, before getting used in Eqn. (3), which is valid only for certain cell operating temperature with corresponding solar irradiation. The output voltage and output current changes with the change in the temperature of the cell and solar irradiation level, therefore it is necessary to consider effect of temperature and solar irradiation levels in final array model. A method given by Buresch [5] includes these two effects i.e. change in cell temperature and solar irradiation level in the PV array modeling. In this method, a model with known temperature and known solar irradiation level is obtained and then it is modified so that it can handle different cases of cell temperature and solar irradiation level.

Let us consider Eqn. (3) as the bench mark model with known operating cell temperature and solar radiation level. The cell operating temperature changes with the change in ambient temperature and irradiation level, which results in new operating voltage and new photo current, therefore it can be said that the output voltage and photo current of the cell is affected by variable ambient temperature. These affects can be seen by the model having temperature coefficients CTU and CTI for the output voltage of the cell and cell photo current respectively.

$$C_{TU} = 1 + \beta_T(T_a - T_x) \qquad (4)$$

$$C_{TI} = 1 + \frac{\gamma_T}{S_c}(T_x - T_a) \qquad (5)$$

Here β_T=0.004 and γ_T=0.06 for the cell used in the model and T_a=20°C, is the cell ambient temperature during the testing of the cell. Therefore modified model of the cell can be obtained for another ambient temperature T_X, if there is no change in ambient temperature during the day time, the irradiation level changes with the change in amount of sunlight during day time and clouds and therefore the output voltage of the cell also changes due to change in solar irradiation level which causes change in photocurrent and operating temperature. The operating temperature increase from T_{x1} to T_{x2} and the cell photocurrent increases from I_{ph1} to I_{ph2} with the increase in soar irradiation level from S_{x1} to S_{x2}, Thus with the variation in solar irradiation level, the change in operating temperature and photocurrent can be expressed through two constants, C_{SU} and C_{SI} which are also known as correction factors for the change in cell output voltage and photocurrent.

$$C_{SU} = 1 + \beta_T \propto_S (S_x - S_c) \qquad (6)$$

$$C_{SI} = 1 + \frac{1}{S_c}(S_x - S_c) \qquad (7)$$

Here S_c is reference solar irradiation level during testing of the cell so that modified cell model can be obtained with the change in solar irradiation there is change in the temperature ΔT_c which is obtained by

$$\Delta T_c = \propto_S (S_x - S_c) \qquad (8)$$

$\propto_S$ is the constant which represents the slope of the change in operating temperature of the cell due to the change in irradiation level and it is equal to 0.2 for the cells used. With the use of all four correction factors i.e. C_{TU}, C_{TI}, C_{SU} and C_{SI}, new values of output voltage of the cell U_{CX} and photo current I_{ph} can be obtained for the new temperature and new solar irradiation T_x and S_x as follows:

$$U_{CX} = C_{TV} C_{SU} U_C \qquad (9)$$

$$I_{phx} = C_{TI} C_{SI} I_{ph} \qquad (10)$$

The current–voltage and power-voltage curves for different temperature and solar irradiation level are shown below in figure 3 & figure 4.

PVA Modelling For Simulink

A general block diagram of the PVA model for GUI environment of Simulink is given in Figure 5 along with filter and load models. The block called PVA model for GUI is the last stage of the model. This block contains the sub models that are connected to build the final model. The PVA consists of 6 PV cells all connected in series to have a desired voltage output. Depending on the load power required, the number of parallel branches can be increased to 2 or more. The effects of the temperature and solar irradiation levels are represented by two variables gains.
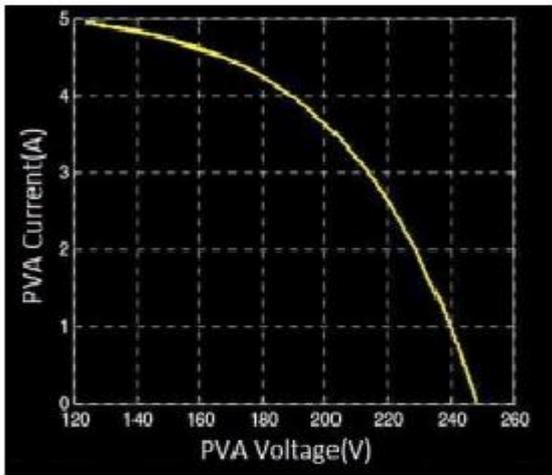
Figure 3. Current-Voltage (I-V) characteristics of PVA
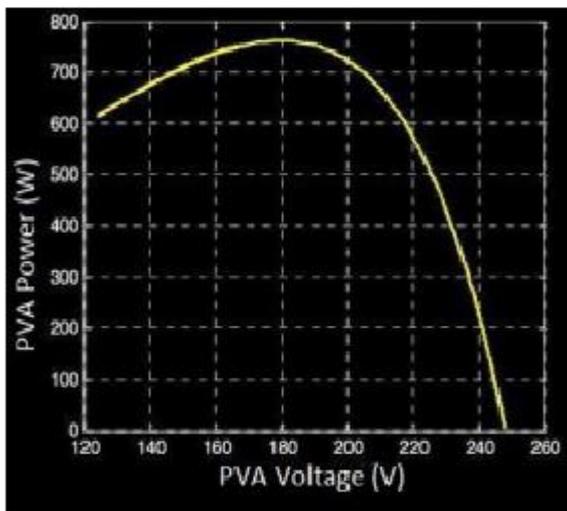
Figure 4. Power-Voltage (P-V) characteristics of PVA

They can be changed by dragging the slider gain adjustments of these blocks named as variable temperature and variable solar irradiation. The last stage of the PVA model is shown below in Figure 5.

The other stages are masked as subsystems under the last stage. The first stage of the PVA modeling is depicted in Fig. 6 where the mathematical model of a single PV cell given by (1) is represented with the block called Equation 1.

The effects of the changing temperature and solar irradiation level are modelled inside the block called Effect of Temperature & Solar Irradiation. This block represents the equations given from (4) to (10) with the modification of (9) and (10) as follows:-

$$U_{CX} = C_U U_C \tag{11}$$

$$I_{phx} = C_I I_{ph} \tag{12}$$

Major inputs and outputs and the conversion of discrete simulation model into continues circuit model are shown in Fig. 7.

Boost Converter

Today DC-DC converters are considered to be of great economic importance [6]. They are one of the few electronic circuits which are used in switching power supplies, widely used in solar systems to provide desired output power [7]. The reliability, efficiency, and controllability of Photo Voltaic (PV) systems can be increased by using boost converter. It can reduce such problems like manufacturing cost, efficiency and

production [8]. It consists of a capacitor and an inductor with energy storing capacity, and two complementary switches. In this type of boost converter the output voltage is higher than the input voltage. The switches are opened and closed alternatively with the rate of PWM switching frequency .Here a closed loop boost converter is given 85.8 volt as input, which is taken from solar panel and boost converter boosts this 85.8 volt DC to 325 volt DC. As shown in Figure 8. Fig. 6 is a sub-mask of the stage 5, which is given in Fig. 7.
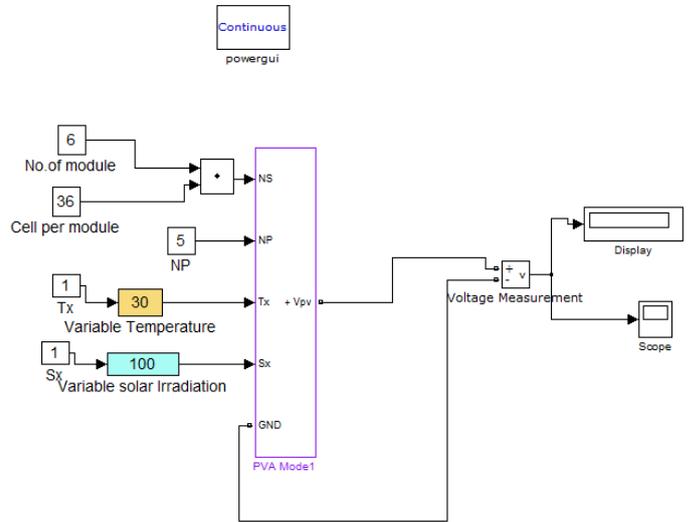
Figure 5. Matlab simulation of solar panel
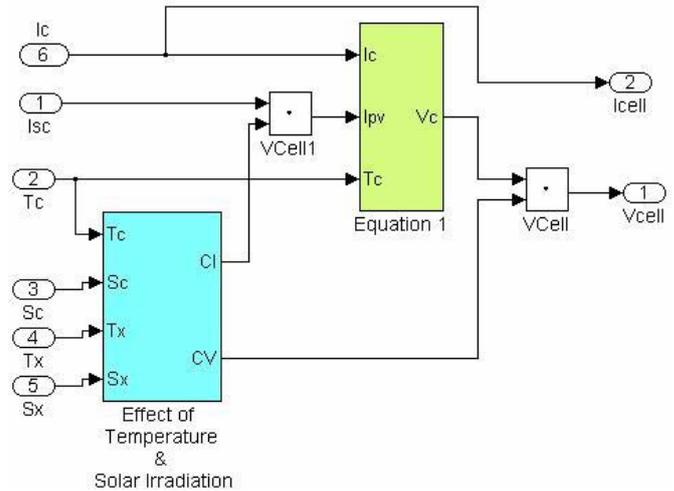
Figure 6. Subsystem 2 of Solar panel
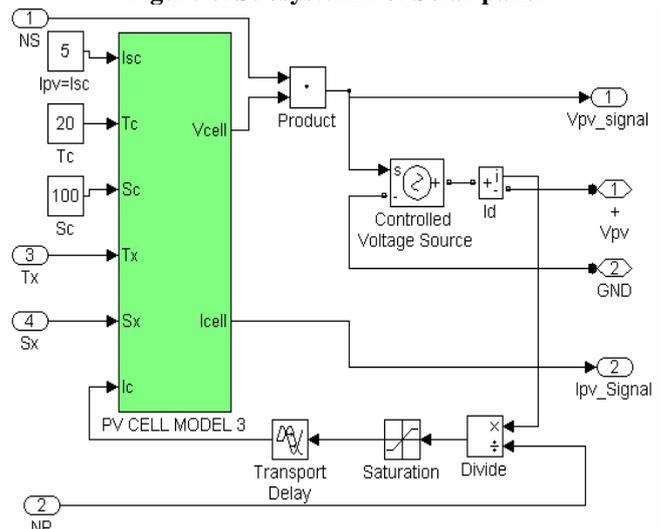
Figure 7. Subsystem 2 of Solar panel
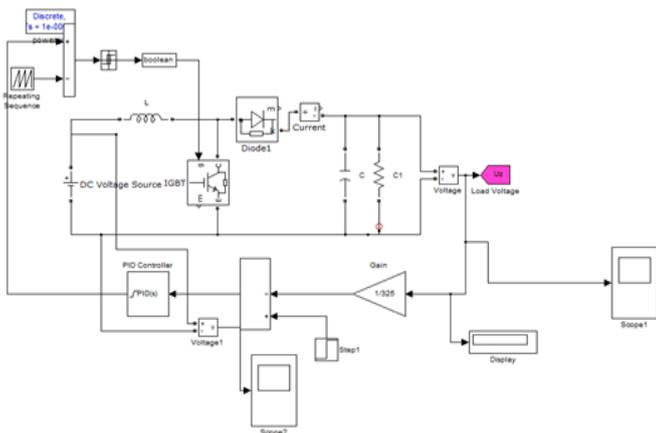
Figure 8. Matlab simulation of closed loop Boost Converter
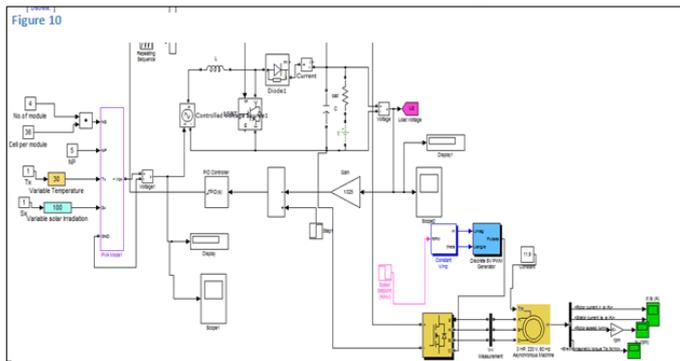
Figure 9. Matlab simulation of closed loop boost converter with 3 phase inverter fed 3 phase induction motor drive

Induction Motor

An induction motor (IM) is an asynchronous AC machine that consists of a stator and a rotor. This motor is widely used because of the rugged construction and moderate cost. In the induction motor a sinusoidal voltage is applied to the stator, this results in an induced electromagnetic field. This field induces a current in the rotor that creates another field that tries to align with the stator field, causing the rotor to spin.

When a load is applied to the motor, a slip is created between these fields. At higher slip values the rotor speed decreases in comparison to the synchronous speed.

The synchronous speed can be controlled by means of the frequency of the stator voltage. By means of power electronics devices the frequency of the voltage applied to the stator can be controlled resulting in an efficient way to control the speed in the motor. The technique used in this paper is using a constant voltage to frequency ratio.

Here number of modules is increased to 6 so that we can get around 85.8 volt output from solar panel, this output is given to closed loop boost converter which is giving constant 325 volt output, this 325 volt is then given to svpwm fed 3 phase inverter, the output of inverter is then given to 3 hp, 220 volt 3 phase induction motor shown in Figure 9.

Simulation Results

Here the solar panel is taking solar energy and converting it into DC output. The simulation given below is of solar panel which is giving DC output of 14.32 (approx.), as shown in figure 10.

The solar panel fed 85.8 volt DC output by increasing no. of modules and cells per module to boost converter which gives 325 volt DC, as shown in figure 11.

We have also given a step change in speed of induction motor through a step input box connected to constant V/Hz control circuit i.e. the speed was 1725rpm for 0.6 sec and then it

decreased to 1300 rpm, and the variation in output due to this can be seen from the waveforms, as shown in figure 12, 13 & 14.

Referring to figure 12, speed waveform of induction motor where speed was 1725 rpm for 0.6 sec and then 1300 thereafter .so from here we can see that speed becomes constant after 1.6 sec.
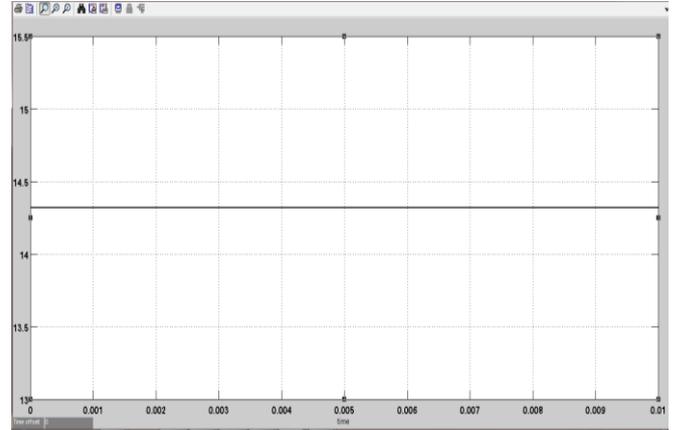
Figure 10. Output of Solar Panel
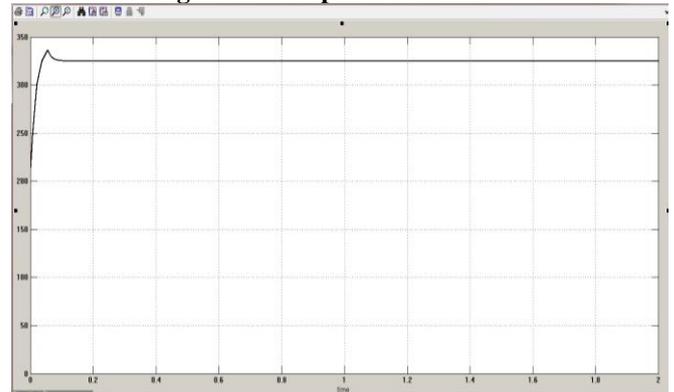
Figure 11. Output of Boost Converter
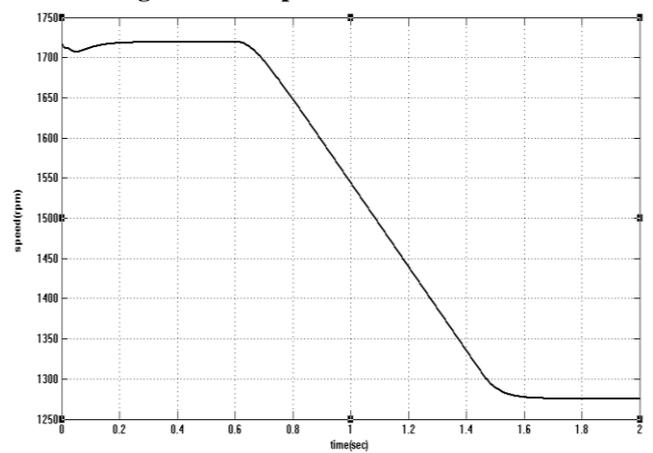
Figure 12. Speed waveform of induction motor

Referring figure 13, we can see that when the change is applied at the speed of 3 phase induction motor at 0.6 sec there is change in stator and rotor current as well for 1.6 sec and then again it becomes constant and the motor starts running at 1300 rpm constantly.

Referring figure 14, we can see the same effect for torque that it decreases at 0.6 sec with decrease in speed and then it also becomes constant after 1.6 sec.

A comparison of Torque speed characteristics is shown in Figure 15 and Figure 16 which clearly depicts that the curves of solar fed induction drive and directly DC source fed induction drive are almost identical.
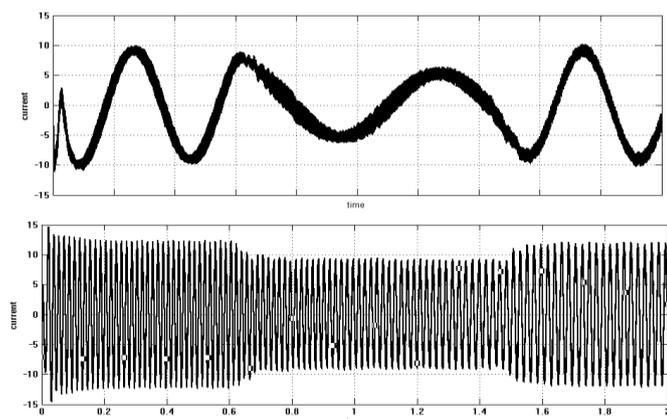
Figure 13. Stator current and rotor current waveform of 3 phase induction motor
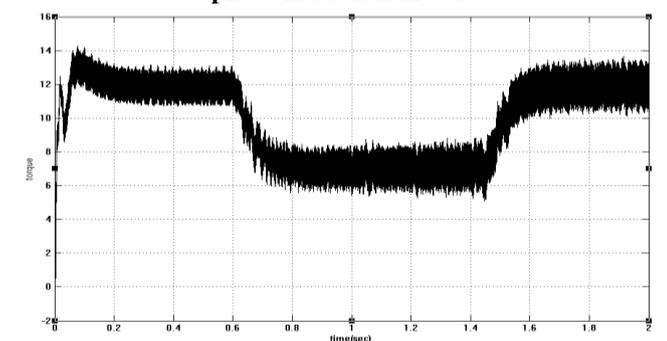
Figure 14. Output waveform of torque
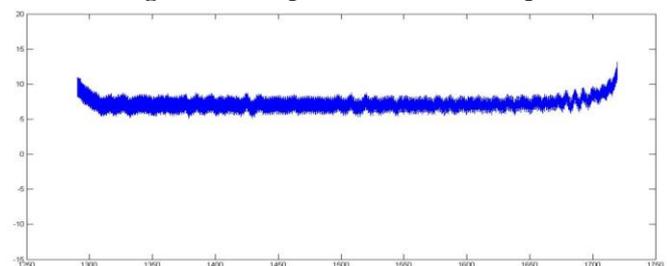
Figure 15. Torque-speed characteristics of induction drive with 325 volt DC source
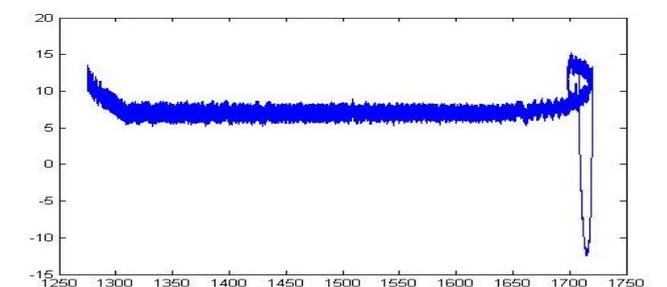
Figure 16. Torque-speed characteristics of induction drive with 325 volt DC from solar fed boost converter

Conclusion

The paper displays the effectiveness and efficiency of output of solar panel when used with boost converter. Its high output voltage can be directly used for DC drives. Further, if it is appended with an additional circuitry like inverter, we can use it at very high level for 3 phase induction motor operation. The paper also describes concept of v-f control which is very helpful in providing good running and good transient performance. Here SVPWM is used to provide pulses to the inverter which helps in AC motor control. Also an investigation on comparison of torque speed characteristics of solar fed induction drive and direct DC voltage fed induction drive is done here which clearly projects that the curves of both the characteristics are almost identical.

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