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IMPLEMENTATION OF PHOTOVOLTAIC CONVERTER FOR WATER PUMPING SYSTEM

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Abstract—This paper proposes a new, low cost DC/DC converter and a inverter driving system for induction motor. The converter is designed to drive a Induction motor directly from Photovoltaic (PV) energy source. The Induction motor is better because of its low cost, reliability, low maintenance and high efficiency. DC output voltage from PV module is converted into AC and is stepped up using a transformer. The output of the transformer is rectified and is fed to a Voltage Source Inverter (VSI) to attain sufficient voltage to drive the motor. As the PV cell posses the nonlinear behavior, the Maximum Power Point Tracker (MPPT) controller is needed to improve the utilization efficiency of the converter. The MPPT algorithm proposed in this paper based on hill climbing algorithm, for matching the load and to boost the PV module output voltage. PI Controller is used to control the pulses and the controlled output is given to the Induction Motor. Here instead of water pump, we have used Induction motor for the ease of operation. The entire system is simulated using Matlab Simulink environment. The system is expected to be operated with high efficiency and low cost for long lifetime.

Keywords— Voltage Source Inverter (VSI), Proportional Integral Controller (PI), Maximum Power Point Tracking (MPPT).

I. INTRODUCTION

The drinkable water is not available for millions of people in various countries due to the non availability of electrical supply in rural areas, where the supply of water is mainly from the rain or from rivers. In such places, the water management through photovoltaic (PV) system is the most efficient and promising way to solve this problem. Even though commercial converters like fuel cell (lead–acid. Lithium-ion batteries) and dc motors available to drive the water pump and giving higher efficiency due to the drawback of the batteries used for pumping system generally have low life span nearly two years which is too low when compared with PV module life of 20 years, requires frequent maintenance and replacement. Whereas PV energy source is cheaper and can reach the poor people need these systems. The design of a motor drive system powered directly from a PV source demands creative solutions to face the challenge of operating under variable power restrictions and still maximize the energy produced by the module and the amount of water pumped. These requirements demand the use of a converter with the following features: high efficiency-due to the low energy available; low cost—to enable its deployment where it is most needed; autonomous operation—no specific training needed to operate the system; robustness—minimum amount of maintenance possible; and high life span—comparable to the usable life of 20 years of a PV panel.

II. PROPOSED CONVERTER

To ensure low cost and accessibility of the proposed system, it was designed to use a single PV module. The energy produced by the panel is fed to the motor through a converter with two power stages: a dc/dc two-inductor boost converter (TIBC) stage to boost the voltage of the panels and a dc/ac three-phase inverter to convert the dc voltage to three-phase ac voltage. This inverter uses Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT) strategies.

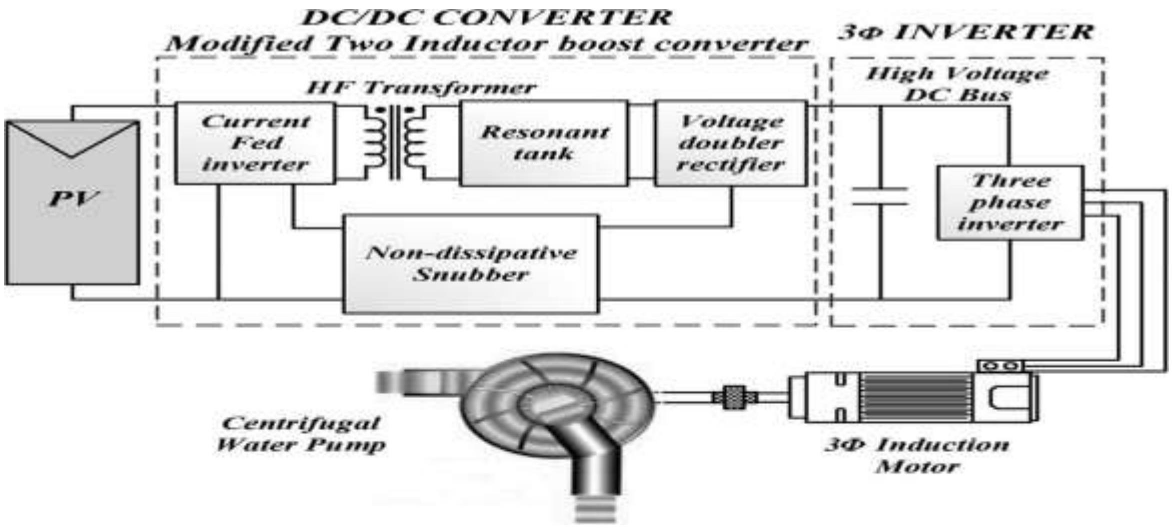

Figure 1. Simplified Block Diagram of the Proposed System

The current-fed converters have input current ripple as low as needed, thus eliminating the need of the input capacitor at the panel voltage and are derived from the boost converter, having an inherent high step-up voltage ratio, which helps to reduce the needed transformer turns ratio. Although the current-fed topologies have all the aforementioned advantages, they still have problems with high voltage spikes created due to the leakage inductance of the transformers and with high voltage stress on the rectifying diodes. One of the solutions to the current-fed PWM converters is the use of resonant topologies able to utilize the component parasitic characteristics, such as the leakage inductance and winding capacitance of transformers, in a productive way to achieve zero current switching (ZCS) or zero voltage switching (ZVS) condition to the active switches and rectifying diodes.

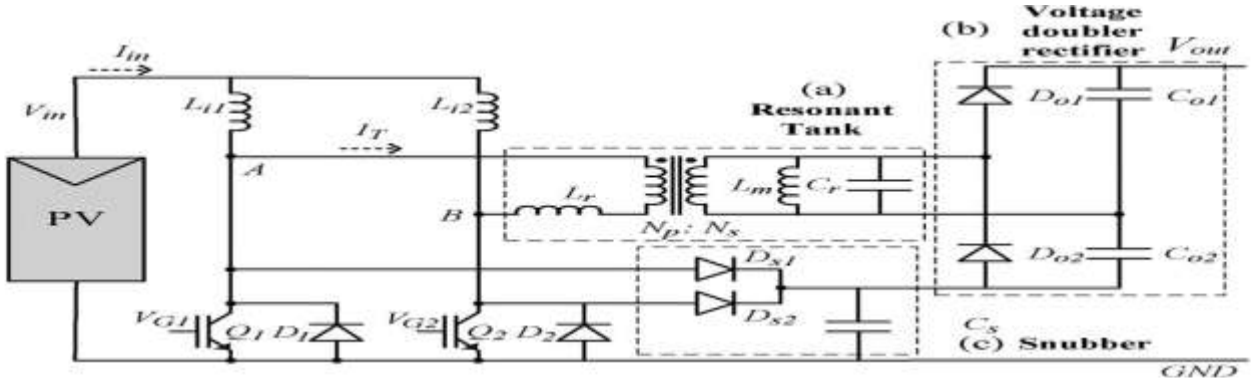

Figure 2. Modified TIBC topology: (a) resonant tank, (b) voltage doubler rectifier and (c) snubber.

In this paper, the use of modified TIBC for the first -stage dc/dc converter is proposed, due to its very small number of components, simplicity, high efficiency, easy transformer flux balance, and common ground gate driving for both switches. These features make it the ideal choice for achieving the system's necessary characteristics. The input current is distributed through the two boost inductors having its current ripple amplitude halved at twice the PWM frequency. This minimizes the oscillations at the PV module operation point and makes it easier to achieve the MPP. A multi resonant tank is formed by the magnetizing inductance of the transformer, its leakage inductance, and the added capacitor, as shown in Fig. 2(a). The intrinsic winding capacitance of the transformer is included in the resonant capacitor.

By adding this capacitor and using the parasitic components of the transformer to create the resonant tank, it is possible to achieve ZCS condition for the input switches and output rectifying diodes, and this enables the converter to operate at high frequencies with greater efficiency. With the use of a voltage doubler rectifier at the secondary side of the transformer, as shown in Fig. 2(b), it is possible to reduce the transformer turns ratio, the necessary ferrite core, and the voltage stress on the

MOSFETs to half of the original ones. As a result, the transformer is cheaper, the MOSFETs are cheaper, and the number of diodes in the secondary side is halved. Also, the output dc bus capacitor can be integrated with the capacitors of the rectifier, particularly because the second- stage three-phase VSI has almost dc input current, exempting the bus capacitor from any ac decoupling current.
The regenerative snubber is formed by two diodes and a capacitor connecting the input side directly to the output side of the converter, as shown in Fig. 2(c). This makes it a non -isolated converter, which has no undesirable effect in the PV motor driver applications. The voltage over the MOSFETs is applied to a capacitor connected to the circuit ground, and the voltage of this capacitor is coupled in series with the output of the rectifier. This modification allows part of the energy to be transferred from the input directly to the output, through the snubber, without going through the transformer, reducing its size and improving even more the efficiency of the converter.

III. OPERATION PRINCIPLE

In the hard-switched operation of the TIBC, the two primary switches Q1 and Q2 operate at an overlapped duty cycle switching scheme to guarantee a conduction path for the primary inductor current. When both Q1 and Q2 are turned on, Li1 and Li2 are charged by the input energy. When Q1(Q2) is opened, the energy stored in Li1(Li2) is transferred to Co1(Co2) through the transformer and the rectifier diode Do1(Do2). Once the multi-resonant tank is introduced, two different resonant processes occur: 1) When both switches are closed, the leakage inductance Lr participates along with capacitance Cr in the resonance at the primary current switching and current polarity inversion, allowing ZCS operation for the primary switches, and 2) during the conduction time interval (between t4 and t5 in Fig. 3), when at least one of the switches is open, Lr is associated in series with Li1 or Li2, not participating on the transformer's secondary current resonance, formed only by Lm and Cr. The key waveforms for a switching period of the TIBC are presented in Fig. 3. In this figure, VgQ1 and VgQ2 are the gate signals of the switches Q1 and Q2, respectively; VdsQ2 is the drain-to-source voltage of MOSFET Q1; IQ2 is the current of MOSFET Q2; VT is the voltage at the primary of the transformer; IT is the current at the primary of the transformer; ILi1 and ILi2 are the currents of inductors Li1 and Li2, respectively; and I_{IN} is the input current of the converter and also the current supplied by the PV panel.

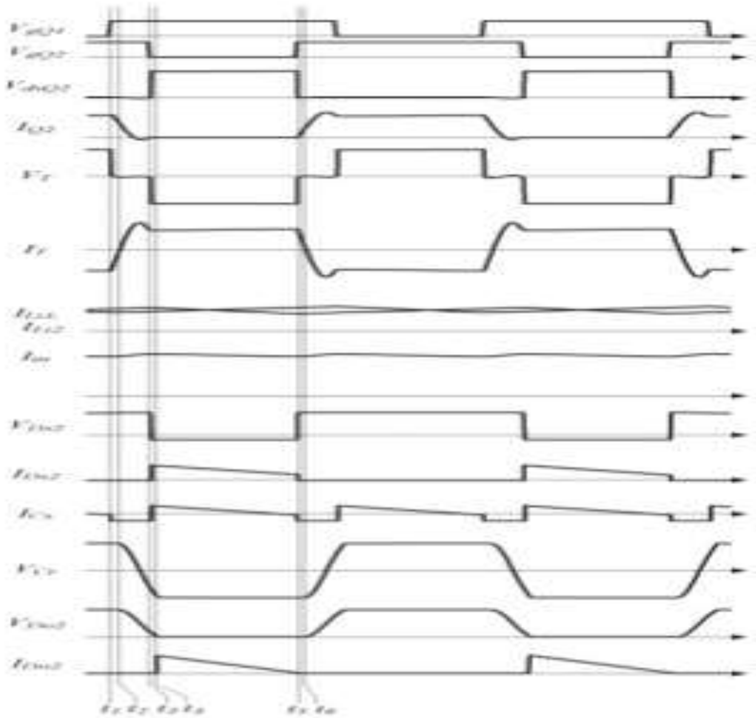

Figure 3. Key waveforms of TIBC during switching period

At time t1, the rectifying diode Do1 is already conducting, and the voltage on resonant capacitor Cr is clamped at $+V_{out}/2$. At this instant, the switch Q1 is activated by VgQ1. As the switch is turned on, its voltage drops to zero, and the snubber diode Ds1 is forced to stop conducting. From t1 to t2, Cr transfers its energy to the leakage inductance Lr, beginning the primary switch's resonant process and forcing the current IQ2 on the switch Q2 to decrease. At the time t2, the rectifying diode Do1 stops conducting, and Cr continues to resonate with the magnetizing inductance Lm. From t2 to t3, the primary switch's resonance (Q2) continues to force its current to decrease until it reverses its polarity. When IQ2 is negative, the switch can be turned off. This happens at instant t3 when VgQ2 is forced to zero. At the time t3, the voltage VdsQ2 starts to increase, Q2 is completely blocked, and the snubber diode Ds2 begins to conduct, transferring energy directly to the snubber capacitor Cs. Between t3 and t4, Cr and Lm continue to resonate, decreasing the voltage on the doubler rectifiers input and on V_{Cr}. At instant t4, the voltage across Cr reaches−Vout/2, and the rectifying diode Do2 starts to conduct, clamping V_{Cr} in −Vout/2.

From t4 to t5, the capacitor Co1 is charged, and the current of Do2 starts to decrease. At the instant t5, Q2 is turned on, initiating the resonant process on Q1. AsQ2 is activated, Ds2 is forced to stop conduction. At the instant t6, the current in Do2 reaches zero, and Do2 stops conducting, reinitiating the resonance between Cr and Lm. From this moment, until the end of the switching period, the process repeats symmetrically as explained for the other input switch.

IV. CONTROL OF THE SYSTEM

There are three main aspects in the proposed converter's control: 1) During normal operation, a fixed duty cycle is used to control the TIBC MOSFETs, thus generating an unregulated high bus voltage for the inverter; 2) an MPP tracking (MPPT) algorithm is used along with a PI controller to set the speed of the motor and achieve the energy balance of the system at the MPP of the PV module; and 3) a hysteresis controller is used during the no-load conditions and start-up of the system. Each of these aspects is described in the following sections.

4.1 Fixed Duty Cycle Control

One of the most important control aspects of this system is the fact that it is possible to use an unregulated dc output voltage and a fixed duty cycle for the first-stage dc/dc converter. As a resonant converter, there are definite time intervals in the switching period for the resonance process to occur. By altering the duty cycle or the switching period to control the output voltage, the converter may no longer operate at ZCS condition.

Therefore, the fixed duty cycle is used to overcome these design problems and ensure that the converter is going to operate in ZCS condition despite the input voltage or output load. The duty cycle was chosen to guarantee that the amount of transferred energy occurs during most part of the switching interval. Therefore, it is possible to transfer the same amount of energy with a smaller rms current. Therefore, the losses in the input inductors ($Li1$ and $Li2$), in the MOSFETs ($Q1$ and $Q2$), and in the transformer are smaller. As a result, the efficiency of the converter improves.

4.2 MPPT Control

The MPPT is a strategy used to ensure that the operating point of the system is kept at the MPP of the PV panel [27]. The widely used hill-climbing algorithm was applied due to its simple implementation and fast dynamic response. This MPPT technique is based on the shape of the power curve of the PV panel. This curve can be divided into two sides, to the left and to the right of the MPP. By analyzing the power and voltage variation, one can deduce in which side of the curve the PV panel is currently operating and adjust the voltage reference to get closer to the desired point.

4.3 Hysteresis Control

The main drawback of the classical TIBC is its inability to operate with no load or even in low-load conditions. The TIBC input inductors are charged even if there is no output current, and the energy of the inductor is lately transferred to the output capacitor raising its voltage indefinitely until its breakdown. Classically, the input MOSFET cannot be turned off because there is no alternative path for the inductor current. However, with the addition of the proposed snubber, the TIBC switches can be turned off. Thus, a hysteresis controller can be set up based on the dc bus voltage level. Every time a maximum voltage limit is reached, indicating a low-load condition, this mode of operation begins. In this case, the switches are turned off until the dc bus voltage returns to a normal predefined level. As a result, the switching losses are reduced during this period of time.

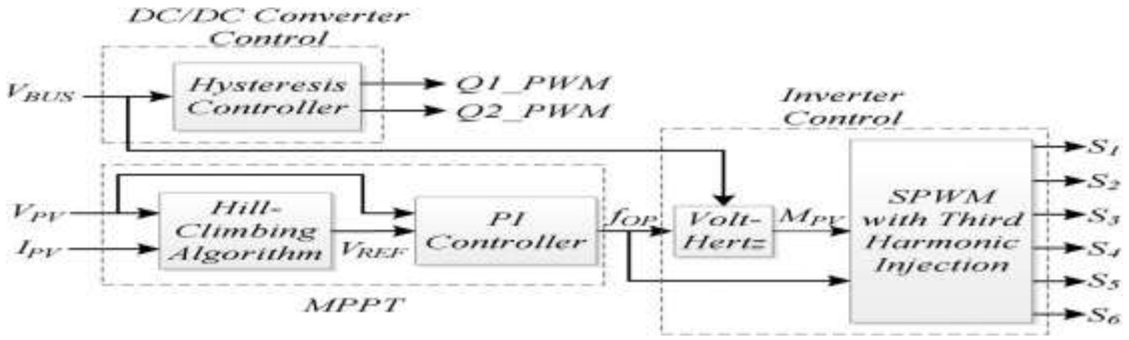

Figure 4. Block Diagram of the Control System

V. SIMULATION CIRCUITS AND RESULTS

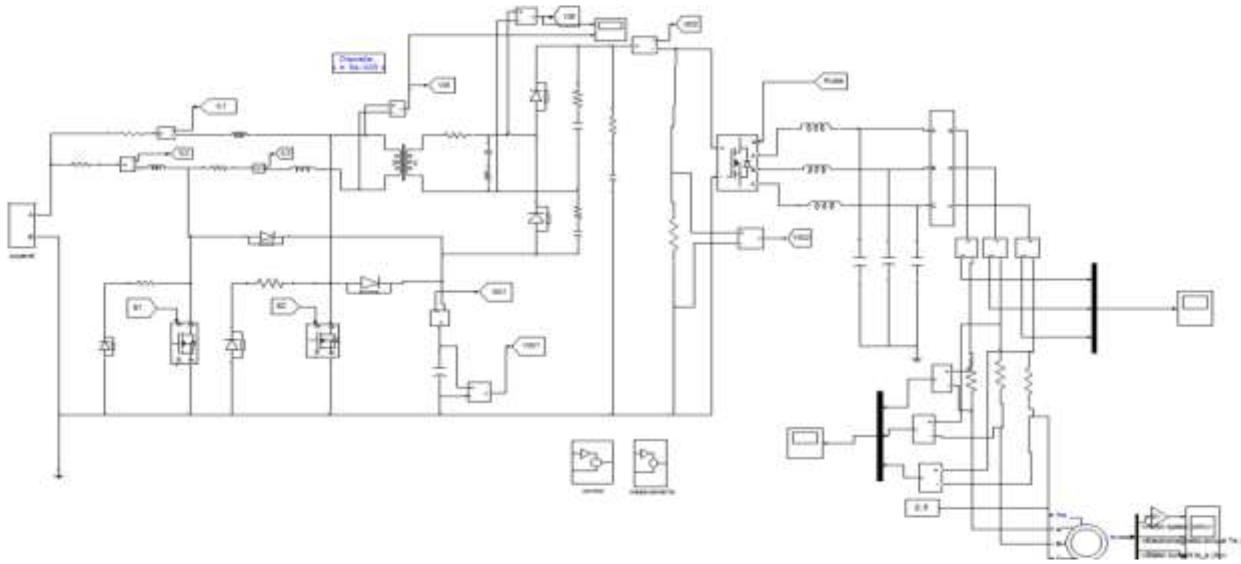

Figure 5. Circuit used for the Implementation of Photovoltaic Converter for Water Pumping System

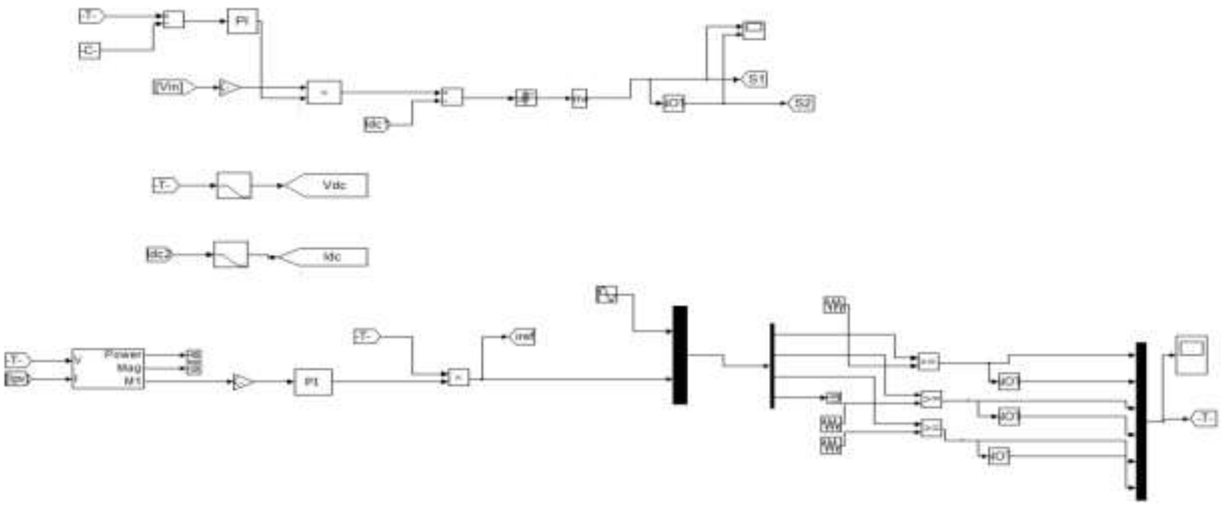

Figure 6. Subsystems used to generate pulses

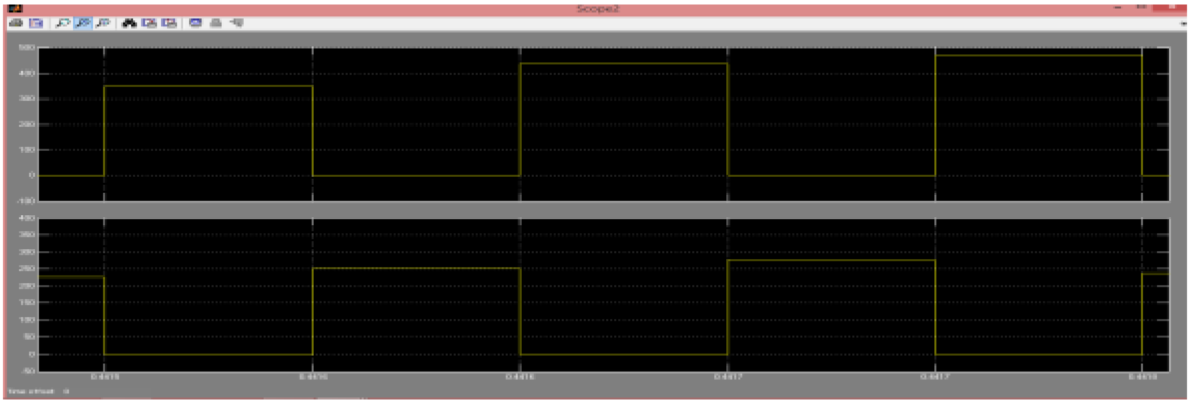

Figure 7. PWM Pulses

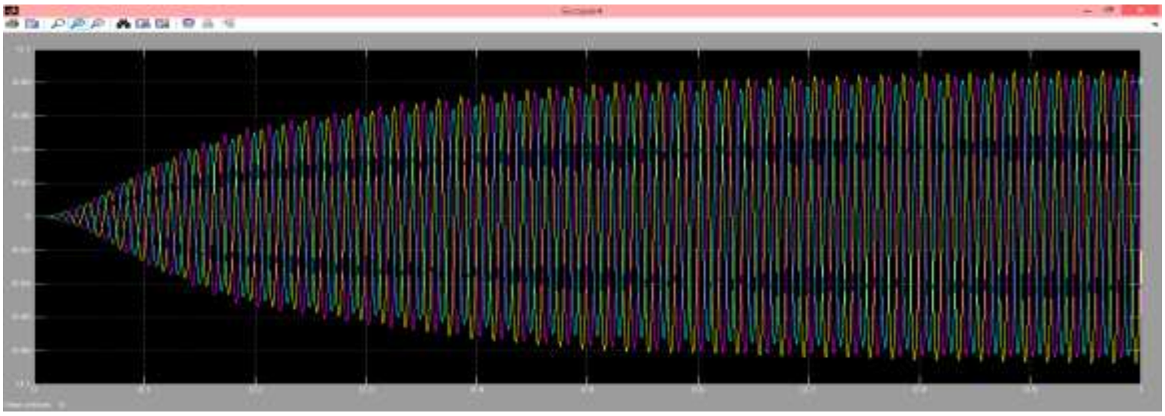

Figure 8. Three Phase Output Voltage

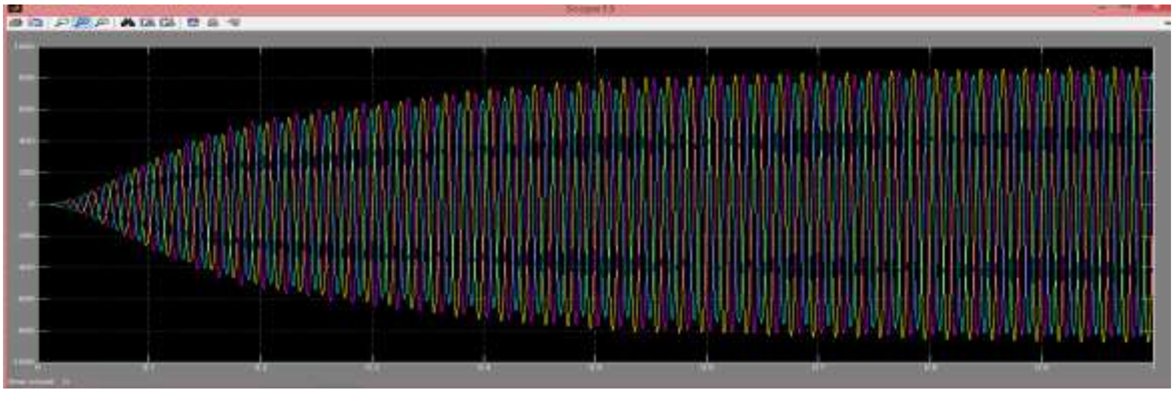

Figure 9. Three Phase Output Current

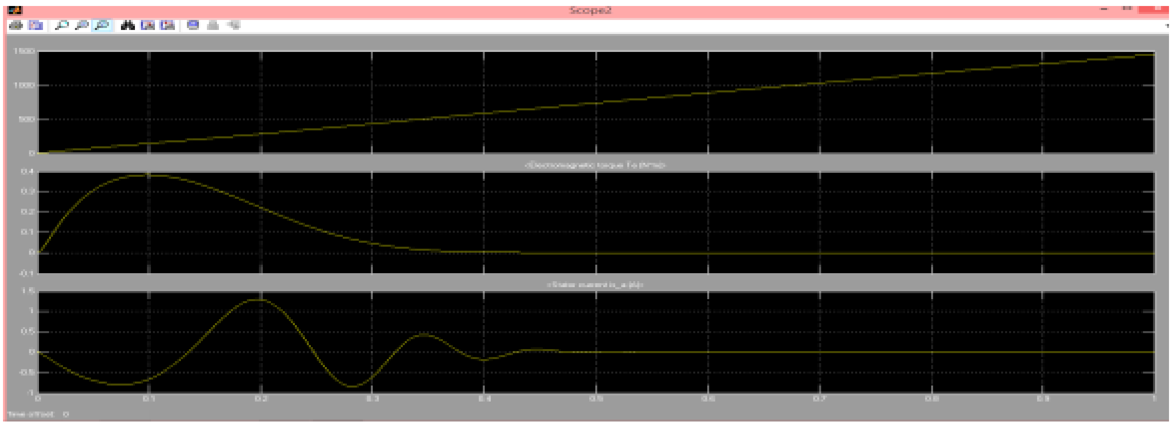

Figure 10. Rotor speed, Electromagnetic torque, Stator current

VI. CONCLUSION

The converter was designed to drive a three-phase induction motor directly from PV solar energy and was conceived to be a commercially viable solution having low cost, high efficiency and robustness. The experimental results suggest that the proposed solution could be a viable option after more reliability tests are performed to guarantee its robustness

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