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# FLC Based Reconfigurable Solar Converter for Induction Motor Drive Hydraulic Pump

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***Abstract:*** *This paper proposes Reconfigurable Solar Converter (RSC) for effective utilization of PV energy. The demand in conventional electricity necessitates the PV power. The incremental conductance based Maximum Power Point Tracking (MPPT) is proposed to obtain maximum power from PV system during varying irradiance and temperature & atmosphere conditions. The main concept of the Reconfigurable Solar Converter is to use a single-stage three phase solar PV converter to perform dc/ac and dc/dc operations. The different operation modes such as PV to Induction Motor drive (dc to ac), PV to battery (dc to dc), battery to Induction Motor drive (dc to ac) and battery & PV to Induction Motor drive (dc to ac) for solar PV systems with energy storage. This converter solution is appealing for PV-battery application, because it minimizes the number of conversion stages, thereby improving efficiency and reducing cost, weight and volume. The Fuzzy Logic Controller (FLC) is applied in this paper for dc/dc operation. In early research the reconfigurable solar converter is used for grid connected system. In this paper it is proposed for grid connected as well as stand-alone system. The hydro pump driven by induction motor for agriculture is proposed as an application in this system.*

*The proposed system is modeled and simulated using MATLAB / Simulink software program.*

**Keywords —** *Reconfigurable Solar Converter (RSC), photovoltaic (PV), Maximum Power Point Tracking (MPPT), energy storage, Induction Motor Drive Hydraulic Pump.*

## I. INTRODUCTION

Solar photovoltaic (PV) electricity generation is not available and sometimes less available depending on the time of the day and the weather conditions. Solar PV electricity output is also highly sensitive to shading. When even a small portion of a cell, module, or array is shaded, while the remainder is in sunlight, the output falls dramatically. Therefore, solar PV electricity output significantly varies. From an energy source standpoint, a stable energy source and an energy source that can be dispatched at the request are desired. As a result, energy storage such as batteries and fuel cells for solar PV systems has drawn significant attention and the demand of energy storage for solar PV systems has been dramatically increased, since, with energy storage, a solar PV system becomes a stable energy source and it can be dispatched at the request, which results in improving the performance and the value of solar PV systems [1]–[4]. There are different options for integrating energy storage into a utility-scale solar PV system. Specifically, energy storage can be integrated into the either ac or dc side of the solar PV power conversion systems which may consist of multiple conversion stages [5]–[34]. This paper uses a novel single-stage solar converter called Reconfigurable Solar Converter (RSC). Fig. 1. shows the overall block of the proposed system. The basic concept of the RSC is to use a single power conversion system to perform different operation modes such as PV to Induction Motor drive (dc to ac), PV to battery (dc to dc), battery to Induction Motor drive (dc to ac), and battery and PV to Induction Motor drive (dc to ac) for solar PV systems with energy storage. Section II introduces the proposed RSC circuit and different modes of operation. In Section III, control of the RSC is introduced and necessary design considerations to the conventional three-phase PV converter. Section IV verifies the RSC with simulation using MATLAB / Simulink that demonstrate the attractive performance characteristics. Section V summarizes and concludes the paper.

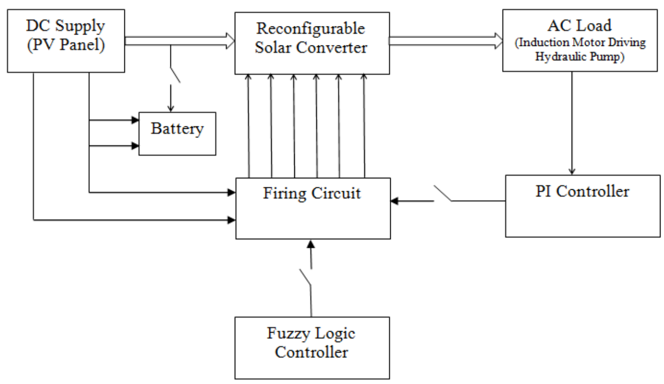


**Fig. 1. Overall block of the proposed system**

## II. RECONFIGURABLE SOLAR CONVERTER (RSC)

### *A. Introduction*

The schematic of the proposed RSC is presented in Fig. 2. The RSC has some modifications to the conventional three-phase PV inverter system. These modifications allow the RSC to include the charging function in the conventional three phase PV inverter system. Assuming that the conventional utility-scale PV inverter system consists of a three-phase voltage source converter and its associated components, the RSC requires additional cables and mechanical switches, as shown in Fig. 2. Optional inductors are included if the ac filter inductance is not enough for the charging purpose.

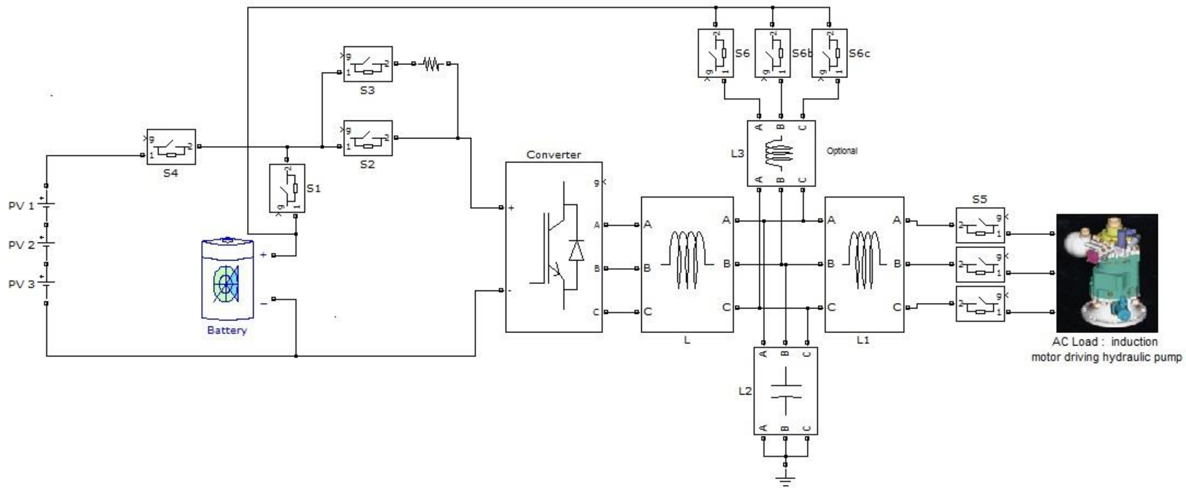


**Fig. 2. Scheme of the proposed RSC Circuit**

***B. Operation Modes***

***Mode 1:*** The PV is directly connected to the Induction Motor drive through a dc/ac operation of the converter with possibility of maximum power point tracking (MPPT) control and the S1 and S6 switches remain open as shown in Fig. 3.

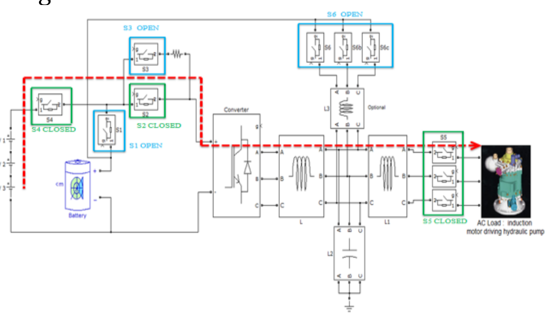

**Fig. 3. PV – Induction Motor drive (dc/ac)**

***Mode 2:*** In Mode 2, the battery is charged with the PV panels through the dc/dc operation of the converter by closing the S6 switch and opening the S5 switch. In this mode, the MPPT function is performed; therefore, maximum power is generated from PV as shown in Fig. 4.

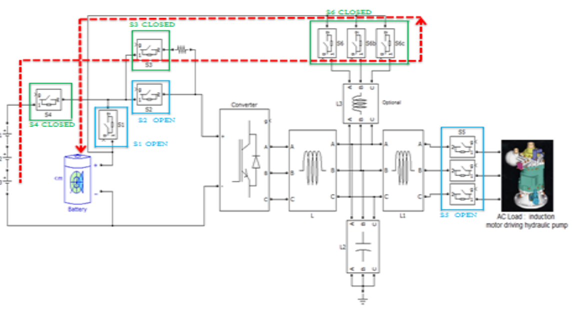

**Fig. 4. PV – Battery (dc/dc)**

***Mode 3:*** In this mode both the PV and battery provide the power to the drive by closing the S1 switch. This operation is shown as Mode 3 is shown in Fig. 5. In this mode, the dc-link voltage that is the same as the PV voltage is enforced by the battery voltage; therefore, MPPT control is not possible.

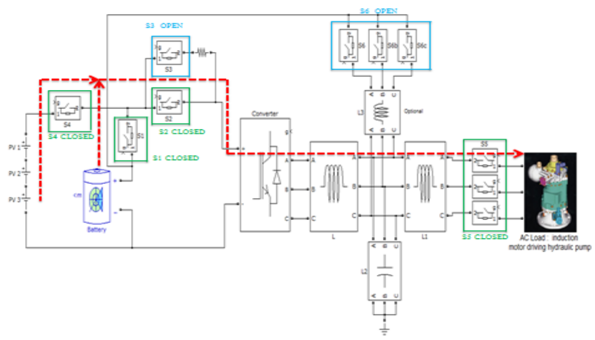

**Fig. 5. PV/Battery–Motor drive (dc/ac)**

***Mode 4:*** In this Mode 4 operation the energy stored in the battery is delivered to the Induction motor drive as shown in Fig. 6.

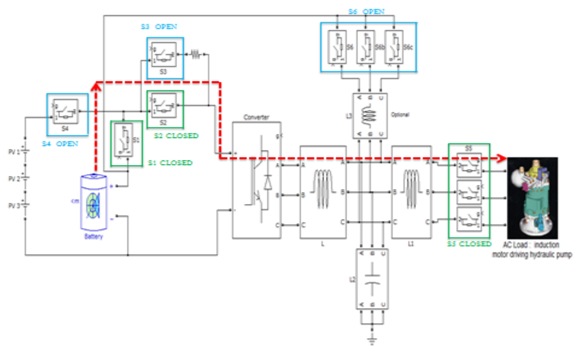

**Fig. 6. Battery– Induction Motor drive (dc/ac)**

***Mode 5:*** In Mode 5, the battery is charged from the grid ac/dc operation of the converter as shown in Fig.7.

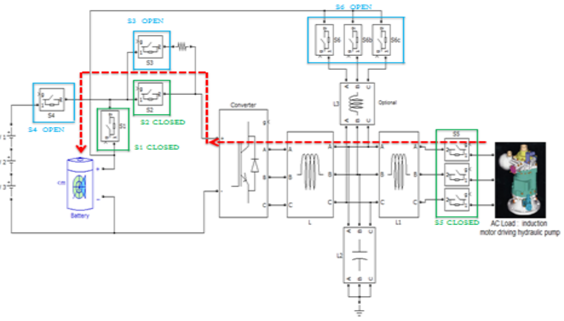


**Fig. 7. Grid - Battery (ac/dc)**

## III. RSC CONTROL

### *A. Control of the RSC in the DC/AC Operation Modes (Modes 1, 3, 4, and 5)*

The dc/ac operation of the RSC is utilized for delivering power from PV to Induction Motor drive, battery to Induction Motor drive, PV and battery to Induction Motor drive and grid to battery. The RSC performs the MPPT algorithm to deliver maximum power from the PV to the Induction Motor drive. The RSC control is implemented with FUZZY LOGIC controller and proportional-integral current control. For the pulse width modulation (PWM) scheme, the conventional space vector PWM scheme is utilized. Fig.8. represents the overall control block diagram of the RSC in the dc/ac operation. For the dc/ac operation with the battery, the RSC control should be coordinated with the battery management system (BMS).

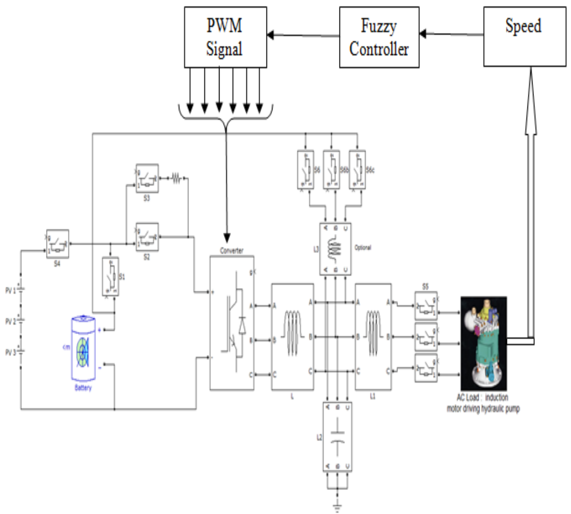


**Fig. 8. Overall control block diagram of the RSC in the dc/ac operation**

### *B. Control of the RSC in the DC/DC Operation Mode (Mode 2)*

The dc/dc operation of the RSC is also utilized for delivering the maximum power from the PV to the battery. The RSC in the dc/dc operation is a boost converter that controls the current flowing into the battery. In this research, Li-ion battery has been selected for the PV-battery systems. Li-ion batteries require a constant current, constant voltage type of charging algorithm. In other words, a Li-ion battery should be charged at a set current level until it reaches its final voltage. At the final voltage, the charging process should switch over to the constant voltage mode, and provide the current necessary to hold the battery at this final voltage. Thus, the dc/dc converter performing charging process must be capable of providing stable control for maintaining either current or voltage at a constant value, depending on the state of the battery. Typically, a few percent capacity losses happen by not performing constant voltage charging. However, it is not uncommon only to use constant current charging to simplify the charging control and process. The latter has been used to charge the battery. Therefore, from the control point of view, it is just sufficient to control only the inductor current. Like the dc/ac operation, the RSC performs the MPPT algorithm to deliver maximum power from the PV to the battery in the dc/dc operation. Fig.9. shows the overall control block diagram of the RSC in the dc/dc operation. In this mode, the RSC control should be coordinated with the BMS.

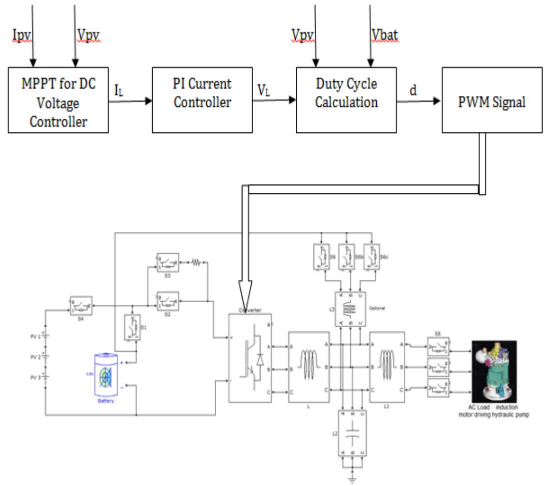


**Fig.9. Overall control block diagram of the RSC in the dc/dc operation.**

### *C. Design Considerations of the reconfigurable solar Converter*

One of the most important requirements of the project is that a new power conversion solution for PV-battery systems must have minimal complexity and modifications to the conventional three-phase solar PV converter system. Therefore, it is necessary to investigate how a three-phase dc/ac converter operates as a dc/dc converter and what modifications should be made. It is common to use a LCL filter for a high-power three-phase PV converter and the RSC in the dc/dc operation is expected to use the inductors already available in the LCL filter. There are basically two types of inductors, coupled three phase inductor and three single-phase inductors that can be utilized in the RSC circuit. Using all three phases of the coupled three-phase inductor in the dc/dc operation causes a significant drop in the inductance value due to inductor core saturation. The reduction in inductance value requires inserting additional inductors for the dc/dc operation. To avoid extra inductors, only one phase can perform the–dc/dc operation. However, when only one phase, for instance phase B, is utilized for the dc/dc operation with only either upper or lower three Metal oxide semiconductor Field effect transistors (MOSFETs) are turned OFF as complementary switching, the circulating current occurs in phases A and C through filter capacitors, the coupled inductor, and switches, resulting in significantly high current ripple in phase B current. To prevent the circulating current in the dc/dc operation, the following two solutions are proposed;

1) All unused upper and lower MOSFETs must be turned OFF;

2) The coupled inductor is replaced by three single-phase inductors.

### D. Mode Change Control

The basic concept of the RCS is to use a single power electronics circuit to perform different operation modes such as PV to Induction Motor drive (dc to ac) and PV to battery (dc to dc) for PV systems with energy storage, as discussed earlier. Therefore, in addition to the converter control in each mode, the seamless transition between modes is also essential for the RCS operation. To change a mode, the RCS must be reconfigured by either disconnecting or connecting components such as the battery through contactors. It is very important to understand the dynamics of the RCS circuit. Specifically, it is essential to understand the relay response time such as how long it takes for a relay to completely close or open. Hence, the performance characteristics of all relays used in the RCS circuit must be investigated with their datasheets. All relays used in the RCS circuit have a maximum operating time equal to or smaller than 50ms. All switching, which occur during mode change, are done under zero or nearly zero current, except fault cases.

## IV. SIMULATION RESULTS OF RSC CIRCUIT

### *A. Simulation Results for DC/AC Operation*

The dc/ac operation of the RSC is utilized for deliver the power from PV to Induction Motor drive, battery to Induction Motor drive, PV and battery to Induction Motor drive. The RSC performs the MPPT algorithm to deliver maximum power from the PV to the Induction Motor drive. The RSC control is implemented with FUZZY LOGIC controller. For the pulse width modulation (PWM) scheme, the conventional space vector PWM scheme is utilized. Fig.10.represents the simulation circuit diagram of the RSC in the dc/ac operation.

### *B. Simulation Results for DC/DC Operation*

The dc/dc operation of the RSC is also utilized for delivering the maximum power from the PV to the battery. The RSC in the dc/dc operation is a boost converter that controls the current flowing into the battery. In this research, Li-ion battery has been selected for the PV-battery systems. Li-ion batteries require a constant current, constant voltage type of charging algorithm. In other words, a Li-ion battery should be charged at a set current level until it reaches its final voltage. At the final voltage, the charging process should switch over to the constant voltage mode, and provide the current necessary to hold the battery at this final voltage. Thus, the dc/dc converter performing charging process must be capable of providing stable control for maintaining either current or voltage at a constant value, depending on the state of the battery.

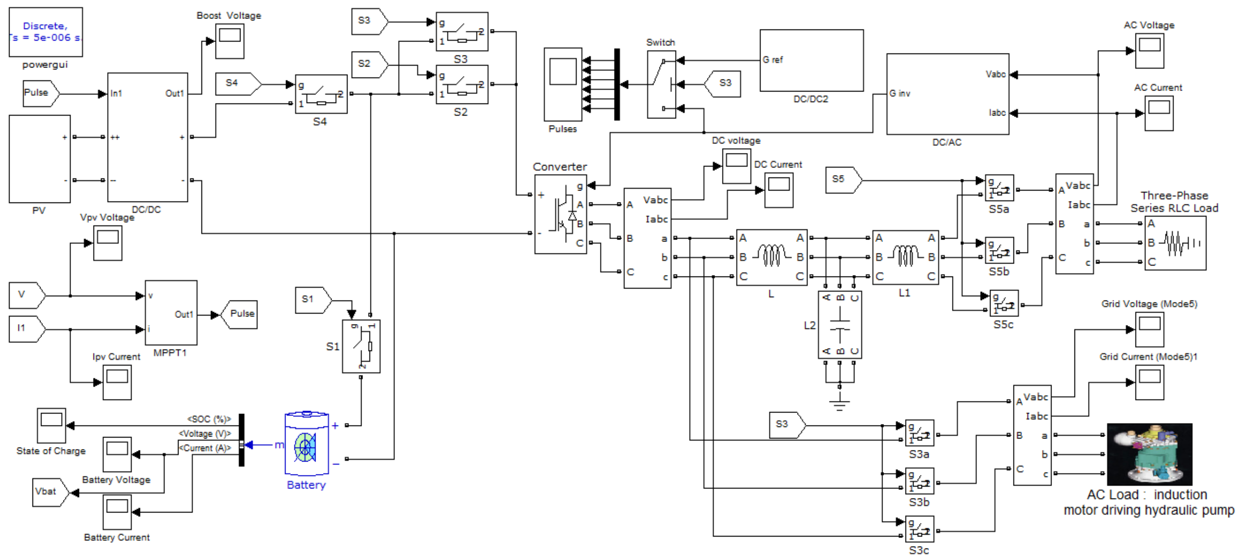


**Fig.10. Simulation circuit diagram of the RSC**

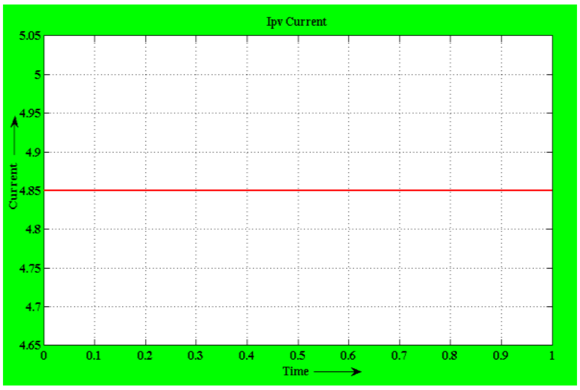


Fig.11. Current from Solar

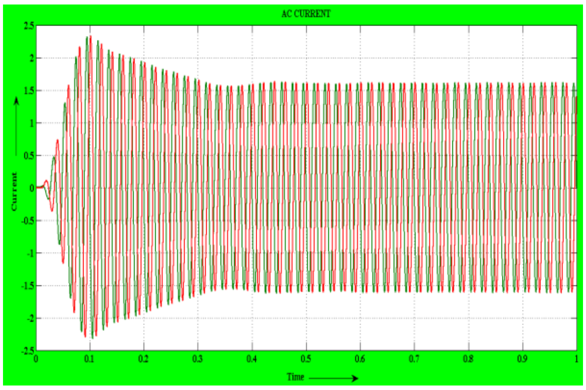


Fig.14. AC Current

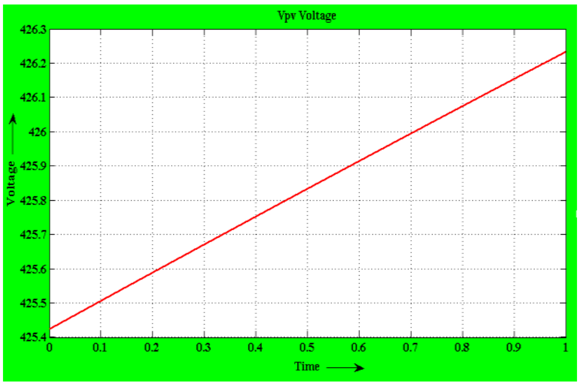


Fig.12. Voltage from Solar

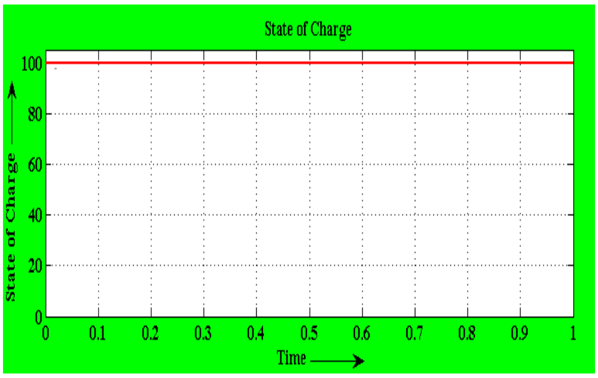


Fig.15. Battery SOC

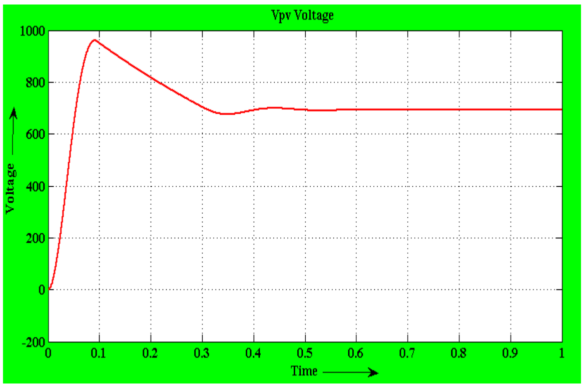


Fig.12. Boost Voltage

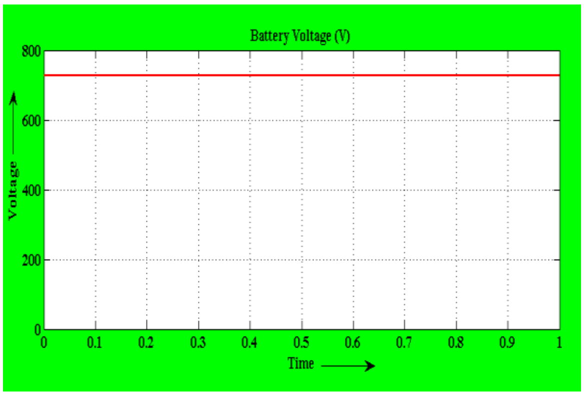


Fig.16. Battery Voltage

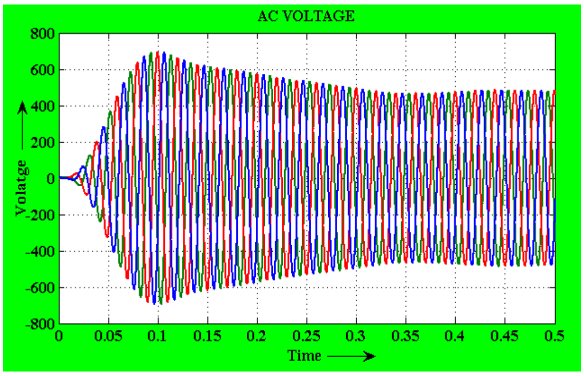


Fig.13. AC Voltage

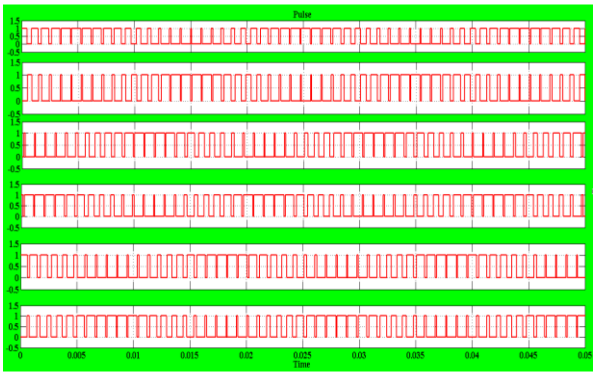

Fig.17. Pulses to IGBT

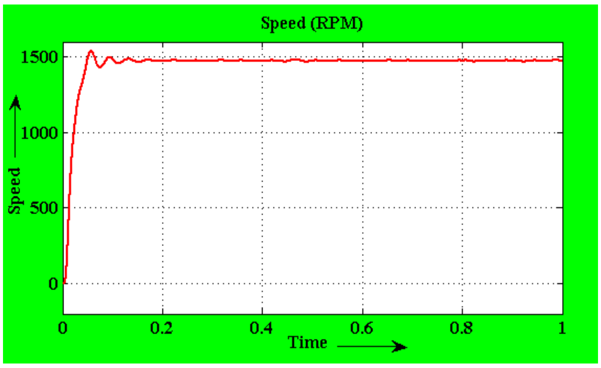


**Fig.18. Speed of Induction Motor**

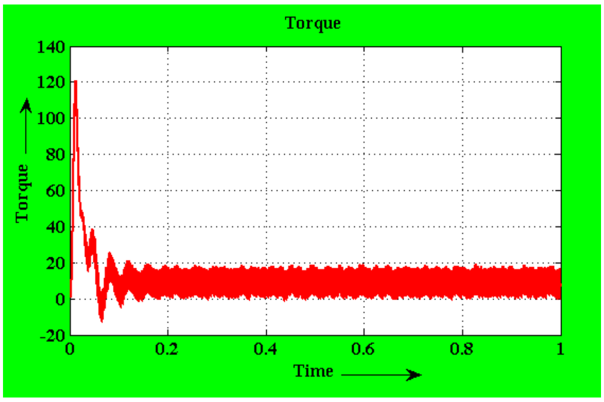


**Fig.19. Torque of Induction Motor**

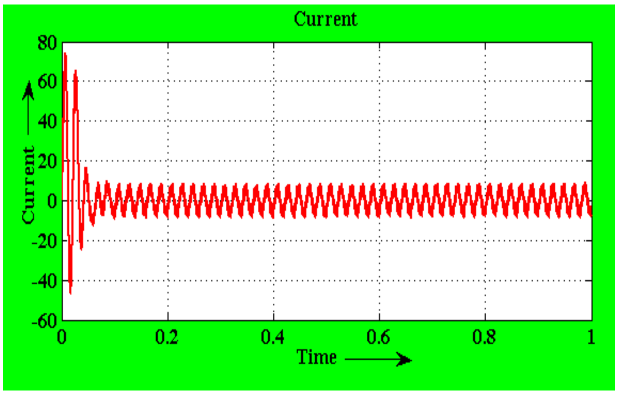


**Fig.20. Stator Current of Induction Motor**

## V. CONCLUSION

This project analysis the main factors that the new converter called RSC Reconfigurable Solar converter used to drive the Induction motor. The basic concept of the RSC is to use a single power conversion system to perform different operation modes such as PV to Induction motor Drive(dc to ac), PV to battery(dc to dc), Battery to Induction motor drive(dc to ac), and PV/battery to Induction motor drive(dc to ac) for solar PV systems with energy storage. The proposed solution requires minimal complexity and modifications to the conventional three phase solar PV converters for PV–battery application. Therefore, the solution is very attractive for PV-battery application, because it minimizes the number of conversion stages, thereby improving efficiency and reducing cost, weight, and volume. Simulation results have been presented to verify the concept of the RSC and to demonstrate the attractive performance characteristics of the RSC. These results confirm that the RSC is an optimal solution for PV battery power conversion systems.

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