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Fuzzy Controller for Solar Reconfigurable Converter Fed BLDC Drive

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Abstract: This paper introduces a new converter called solar reconfigurable converter (SRC) for PMBLDC drive with photovoltaic (PV)-battery application. The basic concept of the SRC is to use a single power conversion system to perform different operation modes such as PV to BLDC drive (dc to ac), PV to battery (dc to dc), battery to BLDC drive (dc to ac), and battery/PV to BLDC drive (dc to ac) for solar PV systems with energy storage. For PMBLDC drive FUZZY LOGIC controller is used to control the motor drive in closed loop. A MPPT technique is also used in DC-DC operation to extract the maximum power from the PV pannel to the battery. In this paper, along the two types of MPPT technique, Incremental conductance algorithm is used for DC/DC operation. PI current controller is used for DC/DC operation(battery charging). 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 effectiveness of this proposed method is verified using matlab/simulink software.

Key words: Solar Reconfigurable Converter (SRC), photo voltaic (PV), BLDC drive, MPPT, Solar power generation.

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[1]-[10]. Solar PV electricity output is also highly sensitive to shading. Therefore, solar PV electricity output significantly varies. 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[11-[25].This paper introduces a novel single-stage solar converter called reconfigurable solar converter (SRC). The basic concept of the SRC is to use a single power conversion system to perform different operation modes such as PV to BLDC drive (dc to ac), PV to battery (dc to dc), battery to BLDC drive (dc to ac), and battery/PV to BLDC drive (dc to ac) for solar PV systems with energy storage.

II. BLDC-PM MACHINE MODEL

Brushless DC (BLDC) motors have the advantage of higher power density than other motors such as induction motors because of having no copper losses on the rotor side and they do not need mechanical commutation mechanisms as compared with DC motors, which results in compact and robust structures. Owing to these features, BLDC motors have become more popular in the applications where efficiency is a critical issue, or where spikes caused by mechanical commutation are not allowed. A BLDC motor requires an inverter and a rotor position sensor to perform commutation process because a permanent magnet synchronous motor does not have brushes and commutators in DC motors.

The electromechanical characteristics of the motor depend directly on the induction value or more exactly on the flux going through the air gap. The rotor is the inductor of the machine and its rotation creates a flux in the air gap. From this flux comes the back-EMF. The back-EMF is the voltage induced in a winding by the movement of the magnet in front of this winding. It is independent of the energy supply to the motor. The back-EMF is directly proportional to the rotation speed, the rotor flux and the number of turns in the corresponding winding.

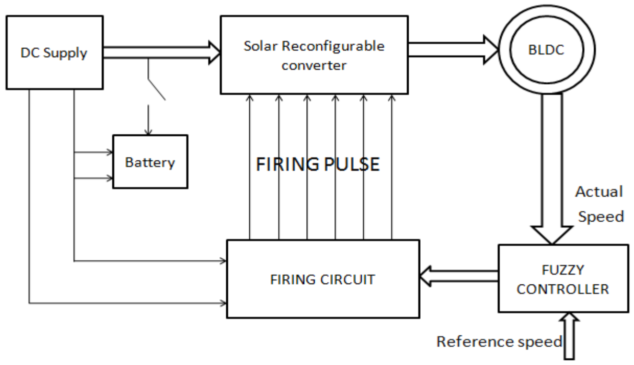

Fig.1.Over all block diagram of the system

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Generally, BLDC-PM motors are driven by a three-phase inverter with what is called six-step commutation. Each phase is conducting 120 electrical degrees. Therefore, for this kind of machine, only two of the three phases are conducting at any time, leaving open the third (floating) phase.Brushless-dc machine operation requires rotor position information to allow for appropriate solid state switch firing. For sensored control, three leading technologies are commonly used to fulfil the position information requirement. These technologies are hall-effect sensors, resolvers, and optical encoders. The most commonly used sensor type is a Hall Effect sensor. They are low cost and provide position resolution to within thirty electrical degrees, which is sufficient to operate a BLDC machine. If precise speed regulation is required, a higher resolution position sensor is needed. Both optical encoders and resolvers offer much higher position resolution.

Many control strategies have been proposed in classical linear theory. As the PMBLDC machine has nonlinear model, the linear PID may no longer be suitable. This has resulted in the increased demand for modern nonlinear control structures like self-tuning controllers, state-feedback controllers, model reference adaptive systems and use of multi-variable control structure. Most of these controllers use mathematical models and are sensitive to parametric variations. Very few adaptive controllers have been practically employed in the control of electric drives due to their complexity and inferior performance.

*F*uzzy controllers have proved to be successful in recent years. These controllers are inherently robust to load disturbances. Besides, fuzzy logic controllers can be easily implemented.

III. PHOTOVOLTAIC ARRAY

A photovoltaic system converts sunlight into electricity. The basic device of a photovoltaic system is the photovoltaic cell. Cells may be grouped to form panels or modules. Panels can be grouped to form large photovoltaic arrays. The term *array* is usually employed to describe a photovoltaic panel (with several cells connected in series and/or parallel) or a group of panels. Most of time one are interested in modeling photovoltaic panels, which are the commercial photovoltaic devices. The term *array* used henceforth means any photovoltaic device composed of several basic cells. The electricity available at the terminals of a photovoltaic array may directly feed small loads such as lighting systems and DC motors.

IV SOLAR RECONFIGURBLE CONVERTER

A. Introduction

The schematic of the proposed SRC is presented in Fig.2 The SRC has some modifications to the conventional three-phase PV inverter system. These modifications allow the SRC 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 SRC requires additional cables and mechanical switches, as shown in Fig.4. Optional inductors are included if the ac filter inductance is not enough for the charging purpose.

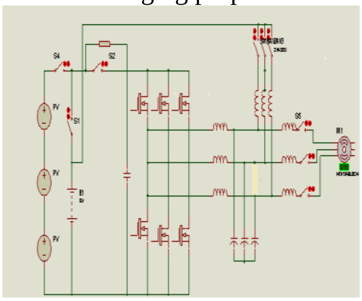

Fig.2. schematic of the proposed SRC

B. Operation Modes

Mode 1: The PV is directly connected to the BLDC drive through a dc/ac operation of the converter with possibility of maximum power point tracking (MPPT) control and the *S*1 and *S*6 switches remain open.

Mode 2: In Mode 2, the battery is charged with the PV panels through the dc/dc operation of the converter by closing the *S*6 switch and opening the *S*5 switch. In this mode, theMPPT function is performed; therefore, maximum power is generated from PV.

Mode 3: There is another mode that both the PV and battery provide the power to the drive by closing the *S*1 switch. This operation is shown as Mode 3. 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.

Mode 4: Mode 4 represents an operation mode that the energy stored in the battery is delivered to the motor drive.

V. SRC CONTROL

A. Control of the SRC in the DC/AC Operation Modes (Modes 1, 3, and 4)

The dc/ac operation of the SRC is utilized for deliver the power from PV to BLDC drive, battery to BLDC drive, PV and battery to BLDC drive. The SRC performs the MPPT algorithm to deliver maximum power from the PV to the BLDC drive. The SRC control is implemented with FUZZY LOGIC controller. For the pulse width modulation (PWM) scheme, the conventional space vector PWM scheme is utilized. Fig.3.represents the overall control block diagram of the SRC in the dc/ac operation. For the dc/ac operation with the battery, the SRC control should be coordinated with the battery management system (BMS).

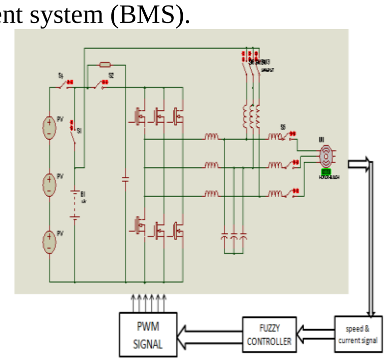

Fig.3. control block diagram of the SRC in the dc/ac operation.

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

The dc/dc operation of the SRC is also utilized for delivering the maximum power from the PV to the battery. The SRC 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 SRC performs the MPPT algorithm to deliver maximum power from the PV to the battery in the dc/dc operation. Fig.7 shows the overall control block diagram of the SRC in the dc/dc operation. In this mode, the RSC control should be coordinated with the BMS.

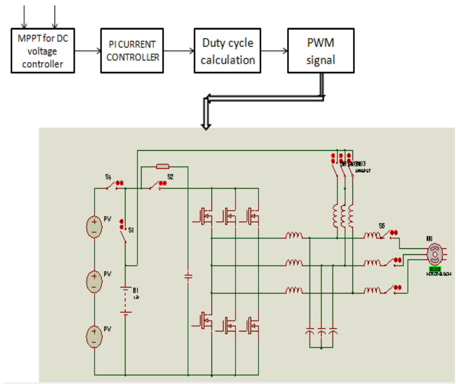

Fig.4.control block diagram of the SRC in the dc/dc operation

C. *Design Considerations of the solar reconfigurable 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 SRC 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 SRC is to use a single power electronics circuit to perform different operation modes such as PV to BLDC 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 SRC operation. To change a mode, the SRC 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 SRC 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 SRC circuit must be investigated with their datasheets. All relays used in the SRC circuit have a maximum operating time equal to or smaller than 50 ms. All switching, which occur during mode change, are done under zero or nearly zero current, except fault cases.

VI. SIMULATION RESULTS OF SRC CIRCUIT

A. *Simulation Results for DC/AC Operation*

The dc/ac operation of the SRC is utilized for deliver the power from PV to BLDC drive, battery to BLDC drive, PV and battery to BLDC drive. The SRC performs the MPPT algorithm to deliver maximum power from the PV to the BLDC drive. The SRC control is implemented with FUZZY LOGIC controller. For the pulse width modulation (PWM) scheme, the conventional space vector PWM scheme is utilized. Fig.5.represents the simulation circuit diagram of the SRC in the dc/ac operation.

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B. *Simulation Results for DC/DC Operation*

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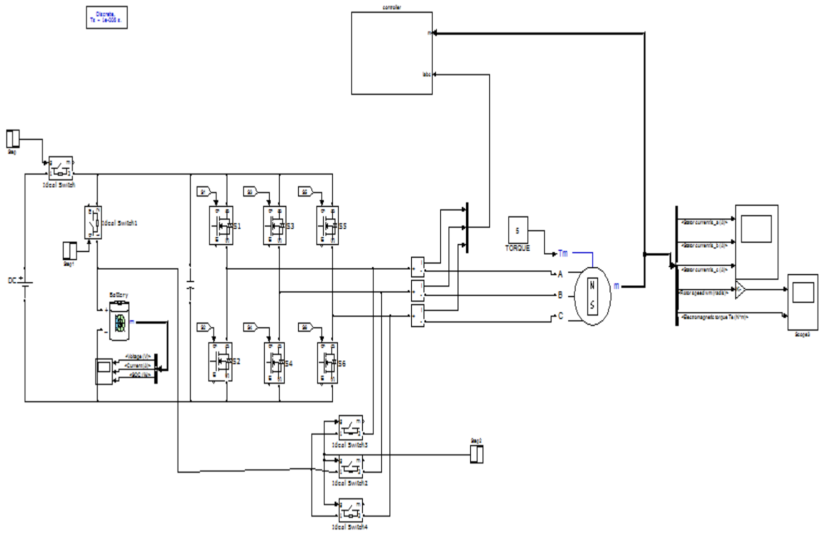

Figure.5 simulation circuit of speed control of BLDC Drive.

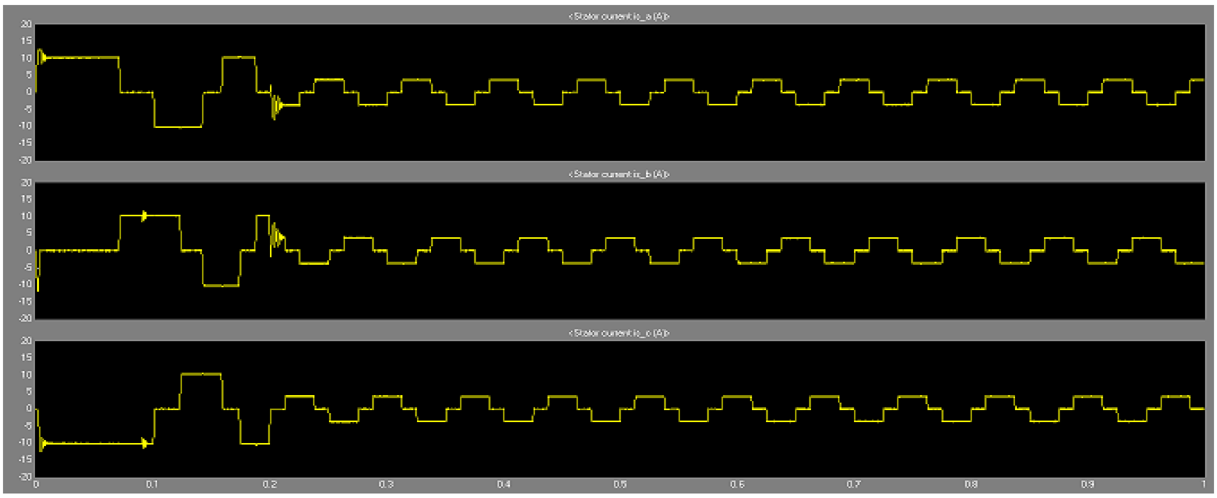

Figure.6. stator currents

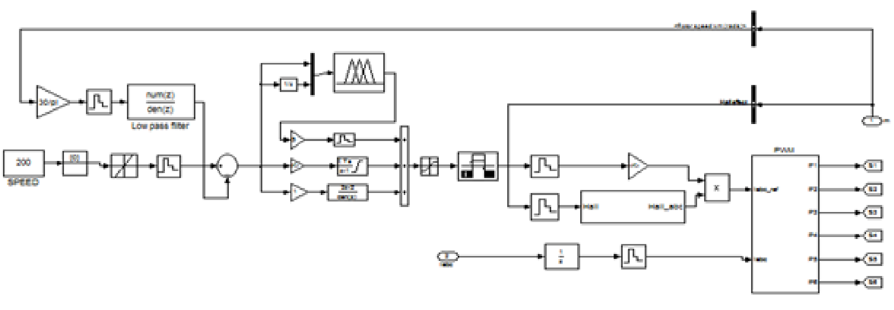

Figure.7.Simulation circuit for FUZZY controller

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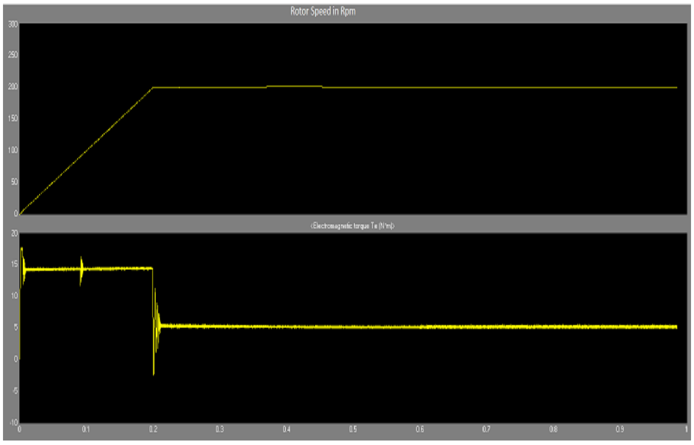

Fig.8. Rotor speed N, Electro Magnetic Torque T_e

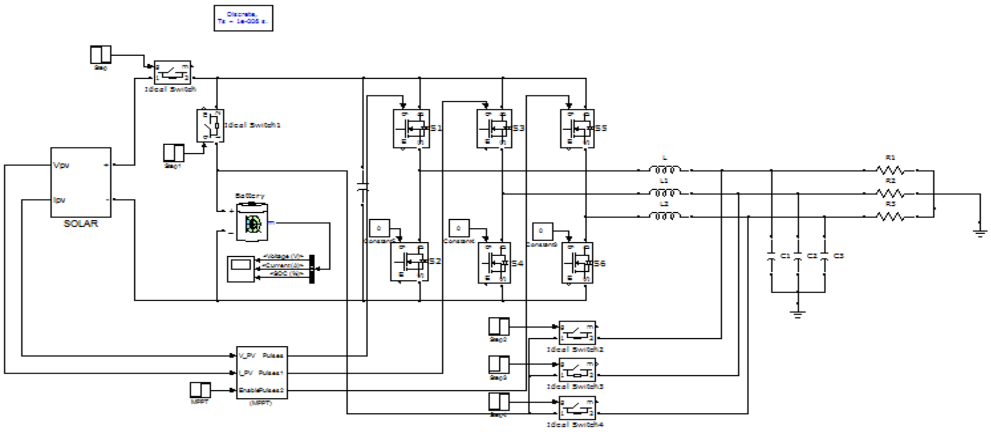

Fig.9.Simulated circuit for DC-DC operation(Battery Charging)

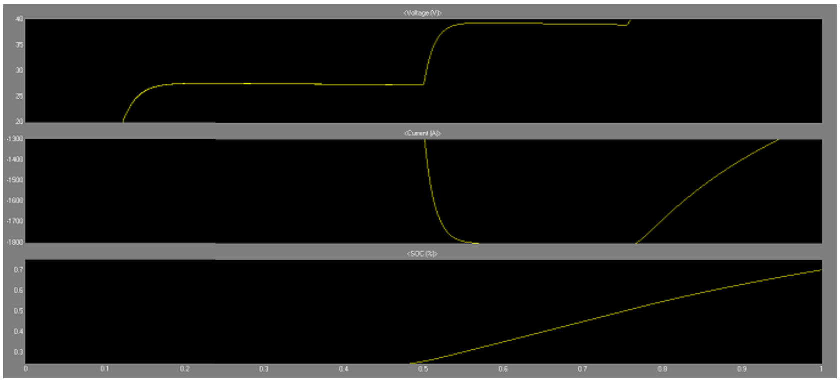

Fig.10. Battery voltage(v), current(I), SOC

VII. CONCLUSION

This project analysis the main factors that the new converter called SRC Solar Reconfigurable converter used to drive the PMBLDC motor. The basic concept of the SRC is to use a single power conversion system to perform different operation modes such as PV to BLDC Drive(dc to ac), PV to battery(dc to dc), Battery to BLDC drive(dc to ac), and PV/battery to BLDC 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 SRC and to demonstrate the attractive performance characteristics of the SRC. These results confirm that the SRC is an optimal solution for PV-battery power conversion systems.

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BIOGRAPHY

Dr.Govindaraj Thangavel born in Tiruppur , India in 1964. He received the B.E. degree from Coimbatore Institute of Technology, M.E. degree from PSG College of Technology and Ph.D. from Jadavpur University, Kolkatta,India in 1987, 1993 and 2010 respectively. His Biography is included in Who's Who in Science and Engineering 2011-2012 (11th Edition). Scientific Award of Excellence 2011 from American Biographical Institute (ABI). Outstandin Scientist of the 21st century by International Biographical centre of Cambridge, England 2011.

Since July 2009 he has been Professor and Head of the Department of Electrical and Electronics Engineering, Muthayammal Engineering College affiliated to Anna University, Chennai, India. His Current research interests includes Permanent magnet machines, Axial flux Linear oscillating Motor, Advanced Embedded power electronics controllers,finite element analysis of special electrical machines,Power system Engineering and Intelligent controllers.He is a Fellow of Institution of Engineers India(FIE) and Chartered Engineer (India).Senior Member of International Association of Computer Science and Information. Technology (IACSIT). Member of International Association of Engineers(IAENG), Life Member of Indian Society for Technical Education(MISTE). Ph.D. Recognized Research Supervisor for Anna University and Satyabama University Chennai. Editorial Board Member for journals like *International Journal of Computer and Electrical Engineering*,International Journal of Engineering and Technology,International Journal of Engineering and Advanced Technology (IJEAT).International Journal Peer

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