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Fuzzy Logic 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. In this paper simulation result can be done using matlab software.

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. 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.

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.

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.

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. Fig. 2 shows an equivalent circuit of the three-phase BLDC-PM motor drive.

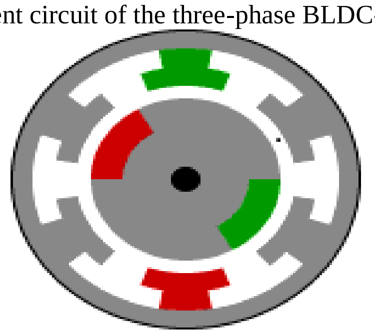

Fig. 1 shows the cross section of the interior PM (IPM)

Brushless Permanent Magnet DC Motors are synchronous motors, their stator flux and rotor mechanical rotation speeds are the same

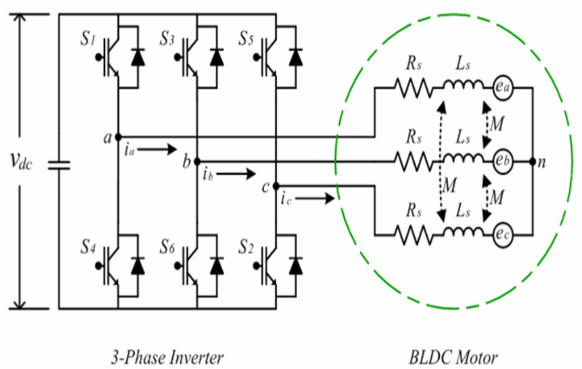

Fig.2.Equivalent circuit of the BLDC drive

– Stator description: 3-phase windings.

– Rotor description: Permanent magnet.

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

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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.

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 fulfill 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. The difference in the two sensors is most evident in their robustness under harsh environments. In general, optical encoders are fragile in comparison to an encoder. Resolvers can easily survive in automotive propulsion applications where high temperature and extreme vibration is common. The position sensor type will always depend on the particular application.

Many control strategies have been proposed [5-7] 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.

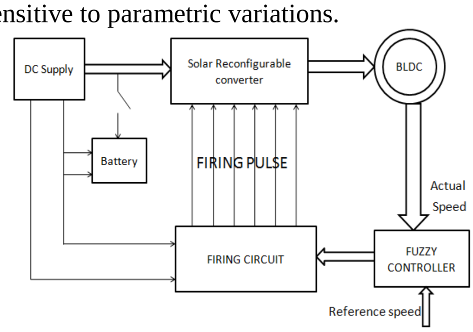

Fig.3.over all block diagram of the system

Very few adaptive controllers have been practically employed in the control of electric drives due to their complexity and inferior performance. Fuzzy controllers [8-10] have proved to be successful in recent years. These controllers are inherently robust to load disturbances. Besides, fuzzy logic controllers can be easily implemented. Fig.3. represents the overall block diagram of the system.

Photovoltaic Array

Introduction to PV 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. Some applications require electronic converters to process the electricity from the photovoltaic device. These converters may be used to regulate the voltage and current at the load, to control the power flow in grid connected systems and mainly to track the maximum power point (MPP) of the device. Photovoltaic arrays present a nonlinear I-V characteristic with several parameters that need to be adjusted from experimental data of practical devices. The mathematical model of the photovoltaic array may be useful in the study of the dynamic analysis of converters, in the study of maximum power point tracking (MPPT) algorithms. The basic equation from the theory of semiconductors that mathematically describes the I-V characteristic of the ideal photovoltaic cell is:

$I = I_{pv,cell} - I_{0,cell}\ [\exp(qV/akT)^{-1}]$

` where Ipv, cell is the current generated by the incident light (it is directly proportional to the Sun irradiation), I_d is the Shockley diode equation, I0,cell [A] is the reverse saturation or leakage current of the diode [A], q is the electron charge [1.60217646 · 10−19C], k is the Boltzmann constant [1.3806503 · 10−23J/K], T [K] is the temperature of the *p-n* junction, and a is the diode ideality constant.

Solar Reconfigurble Converter

A. Introduction

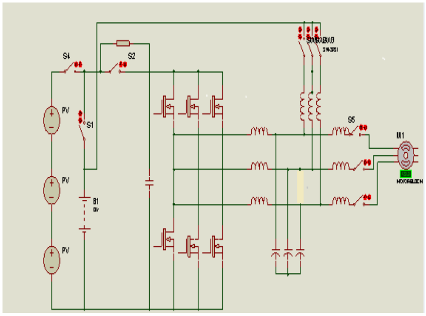

Fig.4. schematic of the proposed SRC

The schematic of the proposed SRC is presented in Fig. 4. 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.

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, the MPPT 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.5.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).

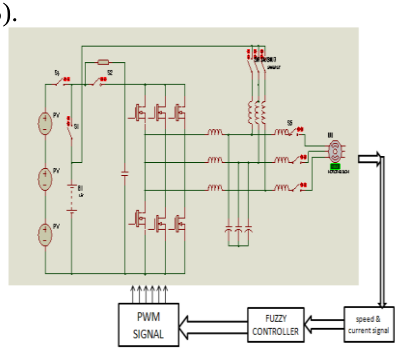

Fig.5. Control block diagram of the SRC in the dc/ac operation.

i)Fuzzy Controller:

Fuzzy logic is a form of many valued logic or probabilistic logic; it deals with reasoning that is approximate rather than fixed and exact. In contrast with traditional logic they can have varying values, where binary sets have two-valued logic, true or false, fuzzy logic variables may have a truth value ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions. Fuzzy logic corresponds to “degrees of truth ”, while probabilistic corresponds to “probability, likelihood”; as these differ, fuzzy logic and probabilistic logic yield different models of the same real-world situations. It incorporating the flexibility of human decision making is used for fuzzy structural operation. To evaluate the input variables with respect to corresponding linguistic terms in condition side. To evaluate the activation strength of every rule base and combine about their sides. By using defuzzification to convert the fuzzy output into precise numerical value.

The fuzzy logic control output Dû(k) is a function is the function of we(n) and Dwe(n) and is expressed as

Dû(k) = FLC [we(n) and Dwe(n)]

where we(n) is the error between reference speed and speed of the motor and Dwe(n) is the change in speed error.

The fuzzy members are chosen as follows:

Positive Big: PB	Negative Big: NB
Positive Medium: PM	Negative Medium: NM
Positive Small: PS	Negative Small: NS
and zero: ZO	

The triangular shaped functions are chosen as the membership functions due to the resulting best control performance and simplicity. The height of the membership functions in this case is one, which occurs at the points –1, -0.57, -0.27, 0, 0.27, 0.57, 1 respectively as shown in Fig.5. An overlap of 50% is provided for neighboring fuzzy subsets. Therefore, at any point of the universe of discourse, no more than two fuzzy subsets will have non-zero degrees of membership. The realization of the function FLC [we(n) and Dwe(n)], based on the standard fuzzy method, consists of three stages:

fuzzification, interference, and defuzzification.

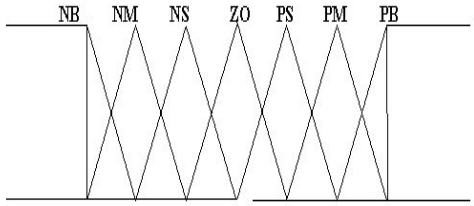

Fig.6. Membrership functions

Fuzzification: This converts point-wise (crisp) data into fuzzy sets (linguistic variable), making it compatible with fuzzy representation.

Interference method: A linguistic rule table according to the dynamic performance of the drive is shown in table 2. The first two linguistic values are associated with the input variables we(n) and we(n -1), while the third linguistic value is associated with the output.

For example, if error in speed is ZO and change in speed error is NS, then output is NM.

Defuzzification: The reverse of fuzzification is called defuzzification. The rules of FLC produce required output in a linguistic variable. Linguistic variables have to be transformed to crisp output. By using the center of gravity defuzzification method, crisp output is obtained.

ii)Pulse-width modulation:

Pulse-width modulation(PWM), or pulse-duration modulation(PDM), is a commonly used technique for controlling power to inertial electrical devices, made practical by modern electronic power switches. The average value of voltage and current fed to the load is controlled by turning the switch between supply and load on and off at a fast pace. The longer the switch is on compared to the off periods, the higher the power supplied to the load is. The PWM switching frequency has to be much faster than what would affect the load, which is to say the device that uses the power. The term duty cycle describes the proportion of ‘on’ time to the regular interval or ‘period’ of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in present, 100% being fully on.

The main advantage of PWM is that power loss in the switching device is very low. When a Switch is off there is practically no current, and when it is on, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases closes to zero.

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.

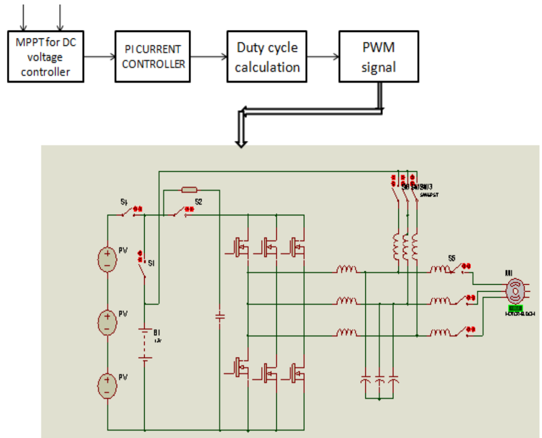

Fig.7.Control block diagram of the SRC in the dc/dc operation

i) MPPT for dc voltage controller:

Maximum Power Point Trackers (MPPTs) play an important role in photovoltaic (PV) power systems because they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency. Thus, an MPPT can minimize the overall system cost. MPPTs find and maintain operation at the maximum power point, using an MPPT algorithm. Many such algorithms have been proposed. However, one particular algorithm, the Incremental Conductance method, continues to be by far the most widely used method in commercial PV MPPTs.

ii)Implementation of Incremental Conductance Method

This method consists in using the slope of the derivative of the current with respect to the voltage in order to reach the maximum power point. To obtain this point, dI/dV must be equal to –I/V. In fact, applying a variation on the voltage toward the biggest or the smallest value, its influence appears on the power value. If the increases, one continues varying the voltage in the same direction, if not, one continues in the inverse direction. The simplified flow chart of this method is given in figure 8

In addition, by using power formula, P=V.I, its derivative becomes :

$dP = V\,dI + I\,dV$

In general, the duty cycle (D) of used DC – DC converter is calculated by the following expression.

$D = D_{old} + deltaD$

Where deltaD is the duty cycle step.

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.

***Fig. 8.* Flow diagram of Incremental Conductance method**

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 which has been marked as “optional” in Fig.4. 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.

While the first solution with a coupled inductor is straightforward, using three single-phase inductors makes it possible to use all three phase legs for the dc/dc operation. There are two methods to utilize all three phase legs for the dc/dc operation:

1) synchronous operation;

2) interleaving operation.

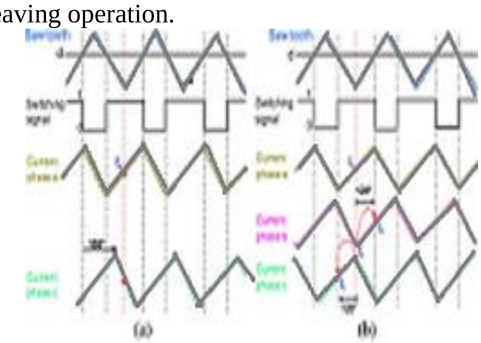

Fig.9. Inductor current

a. Two phase interleaving b. Three phase interleaving

In the first solution, all three phase legs can operate synchronously with their own current control. In this case, the battery can be charged with a higher current compared to the case with one-phase dc/dc operation. This leads to a faster charging time due to higher charging current capability. However, each phase operates with higher current ripples. Higher ripple current flowing into the battery and capacitor can have negative effects on the lifetime of the battery and capacitors.

To overcome the aforementioned problem associated with the synchronous operation, phases B and C can be shifted by applying a phase offset. For the interleaving operation using three phase legs, phases B and C are shifted by 120◦ and 240◦, respectively. The inductor current control in interleaving operation requires a different inductor current sampling scheme, as shown in Fig.8. In general, for digital control of a dc/dc converter, the inductor current is sampled at either the beginning or center point of PWM to capture the average current that is free from switching noises. For two phase interleaving that two phases are 180 ◦ apart, there is no need to modify the sampling scheme, since the average inductor currents for both phases can be obtained with the conventional sampling scheme [see Fig. 8 (a)]. However, for three-phase interleaving, a modified sampling scheme is required to measure the average currents for all three phases. Therefore, the sampling points for phases B and C must be shifted by 120◦ and 240◦, respectively [see Fig. 9(b)], which may imply that computation required inductor current control for each phase should be done asynchronously. Using the interleaving operation reduces the ripples on the charging current flowing into the battery. Therefore, the filter capacitance value can be reduced significantly.

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.

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.10.represents the simulation circuit diagram of the SRC in the dc/ac operation.

B. Simulation Results for DC/DC Operation

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.

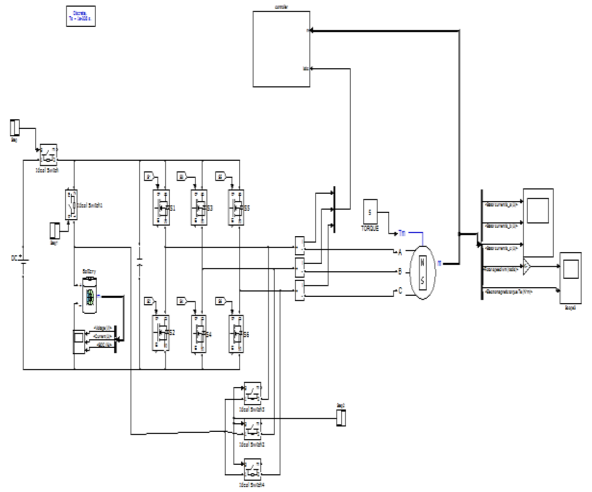

Figure.10 simulation circuit of speed control of BLDC Drive.

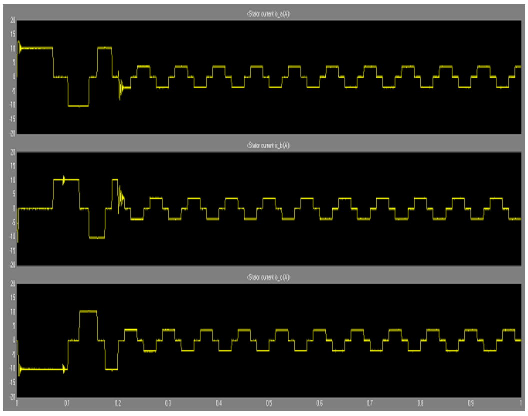

Figure.11. stator currents I_a, I_b, I_c ,

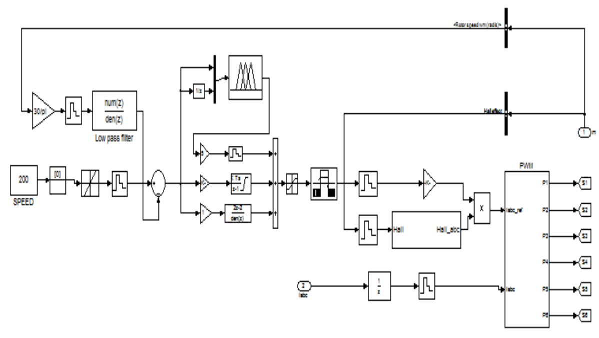

Figure.12.Simulation circuit for FUZZY controller,

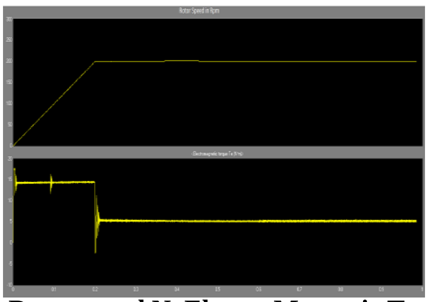

Fig.13. Rotor speed N, Electro Magnetic Torque T_e

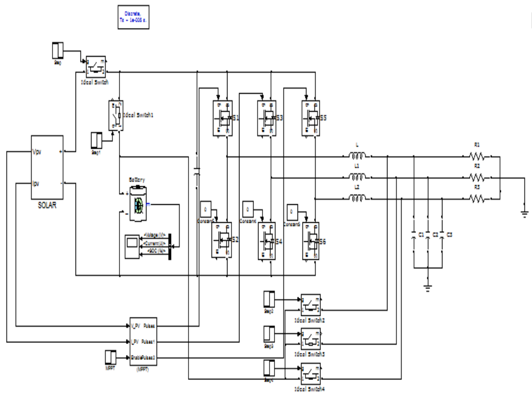

Fig.14.Simulated circuit for DC-DC operation(Battery Charging)

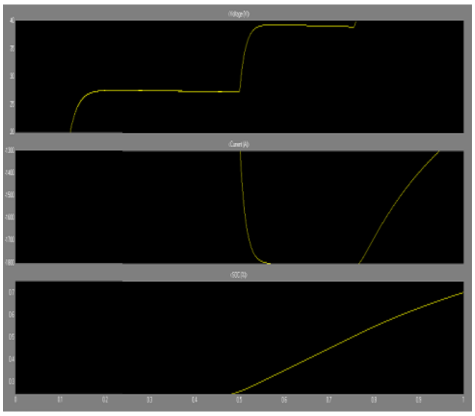

Fig.15. Battery voltage(v), current(I), SOC

Conclusion

This project analysis the main factors that the new converter called RSC Reconfigurable solar converter used to drive the PMBLDC motor. The basic concept of the RSC 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. Although this paper focuses on three-phase application, the main concept can be applied to single-phase application. The proposed solution is also capable of providing potential benefits to other intermittent energy sources including wind energy.

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