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SIMULATION BLDC MOTOR FED BY SEPIC CONVERTER FOR CONTROL OF PV

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ABSTRACT:

1. Abstract: Brushless DC (BLDC) motors are now widely used in many industrial and domestic applications due to their significant advantages in terms of size, weight, torque and efficiency against any other type of motor. Most of the domestic appliances including refrigerators, fans and washing machines use BLDC motors in them. Moreover, photovoltaic (PV) inverters are being installed in more houses than ever which in-turn make BLDC motors more suitable in home appliances and can be seen as imminent future. However, PV due to its inherent nature is intermittent in its operation and requires an efficient DC-DC converter to control its output for its smooth operation. This paper proposes a bridgeless single switch single ended primary inductance converter (SEPIC) converter which serves as a better alternative to Buck-Boost and Cuk converter as it eliminates use of diode bridge rectifier at front end and thus lowers the conduction loss. A closed loop speed control technique is also introduced for control of BLDC motor to make it more practical for various applications and is verified using MATLAB/Simulink and a hardware prototype using Arduino. Results obtained from software and hardware prove the usefulness of the proposed scheme.

KEYWORDS: BLDC Motor, MATLAB/Simulink, PV System, SEPIC Converter.

I INTRODUCTION

Brushless DC (BLDC) motors are fast replacing brushed dc and induction motors among various applications owing to their superior performance, high torque, high flux density, maintenance free operation, low noise and high power density to weight ratio [1-2]. They can come in small sizes as well and in a growing solar photovoltaic environment are more suitable for home appliances which work on DC power or require inverter operation.

Photovoltaic is becoming most promising of the energy source and has penetrated not only among industries but regular residential premises in last ten years [2]. However, these systems face uncertainty of electricity production due to huge dependence on weather conditions which result in intermittent operation.

This causes power quality loss among applications and may result in failure of the appliance with motors in it or may cause unsatisfactory performance of the same while also reducing its lifespan. To overcome these issues, an efficient DC-DC converter with fast dynamic performance is necessary as BLDC motors have similar characteristics and the power supply must be able to match it. If power supply is not robust, back-emf developed due to operation of BLDC motor may damage the power supply system [3]. BLDC motors have been of tremendous interest among researchers since the last decades and it evident from publication on the same. Basic mathematical model of BLDC motor is covered in [4-7] while its operation, working and implementation is described in [8-10]. Solar PV generation has increase multifold in recent times. Moreover, its maximum power point tracking techniques have also been implemented to extract maximum output from the solar panels [11-15]. Many DC-DC converter topologies were established prior to introduction of SEPIC converter. Buk, boost, buck-boost, Cuk are some of the strategies implemented earlier [15-20] which suffered heavy losses or had a negative voltage output or had only voltage booster or controlled voltage below the input levels. SEPIC converter on the other hand gives flexibility to be used to control voltage in very large range with higher efficiency [21-28]. Moreover, many researchers have used SEPIC converter with BLDC motors [29-34] due to its superior dynamic performance.

This paper presents simulation of a PV fed bridgeless single switch SEPIC converter for control of a low power BLDC motor suitable for home appliances. Proposed technique is highly efficient and easier to control and provides smooth operation in a PV fed scenario. The paper is organized as follows: Section I introduction is immediately followed by mathematical modelling in section II. The scheme of implementation is discussed in section III whereas results from MATLAB/Simulink are discussed in section IV and V respectively. Section VI concludes the paper.

II. MATHEMATICAL MODELLING

A. BLDC Motor

BLDC motor consists of a permanent magnet rotor similar to a PMDC motor but a three phase stator winding similar to an induction motor.

This arrangement enables motor to be run by a three phase inverter and thus torque produced by this motor is much higher as compared to both DC and induction motors. A typical construction of a BLDC motor is shown in Fig. 1. It also consists of three Hall sensors mounted 120o apart from each other so as to accurately determine the rotor position required for its operation.

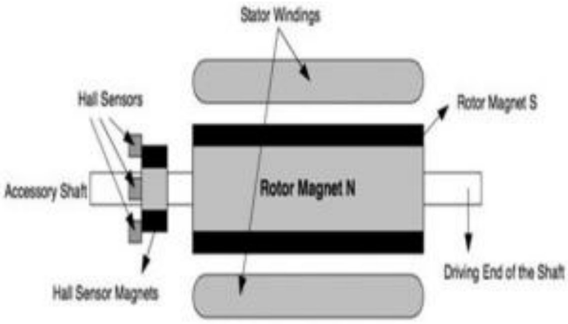

Fig. 1. BLDC motor construction with Hall Sensor arrangement.

Mathematical model of a BLDC motor is given below:

$$\begin{aligned}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \\ \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix}\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}\end{aligned} \qquad (1)$$

where va , vb, vc are the phase voltages, ia , ib, ic are the phase currents, ea , eb, ec are the phase back-EMF waveforms, R is the phase resistance, L is the self-inductance of each phase and M is the mutual inductance between any two phases. So the electromagnetic torque can be obtained as:

$$T = (e i + e i + e i)/\omega \qquad (2)$$

where ωr is the mechanical speed of the rotor and Te is the electromagnetic torque. The equation of motion is:

$$\frac{d}{dt}\omega_r = (T_e - T_L - B\omega_r)/J \qquad (3)$$

B is the damping constant, J is the moment of inertia of the drive and TL is the load torque. The electrical frequency related to the mechanical speed for a motor with P numbers of poles is:

$$\omega_e = (P/2)\omega_r \qquad (4)$$

B. Photovoltaic System

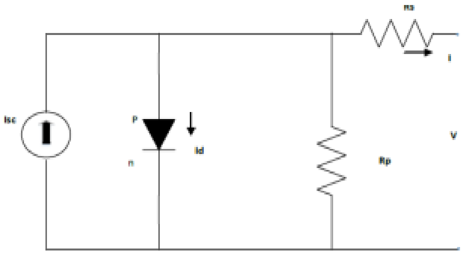

Fig. 2. PV cell equivalent circuit

The equivalent circuit diagram of a single PV cell is shown in Fig. 2. The current source Iph represents photocurrent, Rsh and Rs are the intrinsic shunt and series resistances, respectively. Usually the value of Rsh is very large and that of Rs is very small, hence they may be neglected to simplify the circuit analysis. Practically, PV cells are grouped in larger units called PV modules and these modules are connected in series or parallel to create PV arrays which are used to generate electricity in PV generation systems. The equivalent circuit for PV array is shown in Fig. 3. The voltage-current characteristic equation of a solar cell is provided as:

Module photo-current Iph:

$$I_{ph} = [I_{sc} + K_i(T - 298)] * I_r / 1000 \qquad (5)$$

where,

Iph: photo-current (A);

Isc: short circuit current (A);

Ki: short-circuit current of cell at 25oC and 1000 W/m2 ;

T: operating temperature (K);

Ir: solar irradiation (W/m2).

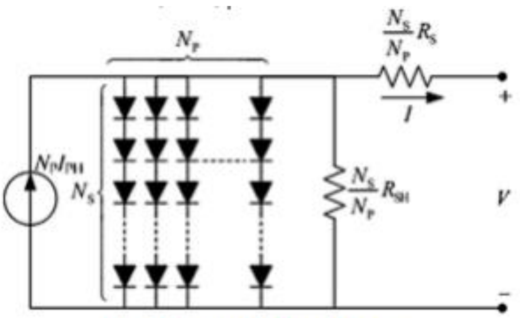

Fig.3. Equivalent circuit of solar array

Module reverse saturation current Irs:

$$I_{rs} = [I_{sc} / \exp(qV_{oc} / N_s knT - 1] \qquad (6)$$

where,

q: electron charge, = 1.6 × 10-19C;

Voc: open circuit voltage (V);

Ns: number of cells connected in series;

n: the ideality factor of the diode;

k: Boltzmann's constant = 1.3805 x 10-23 J/K.

C. SEPIC Converter

SEPIC converter circuit with ideal switches is shown in Fig. 2. It allows output to be greater than, less than or equal to input voltage which can be controlled by duty cycle given to S1.

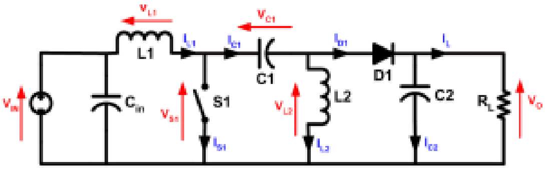

Fig. 3. Circuit Diagram of SEPIC Converter with ideal switches

In continuous mode of conduction, its voltage equation is given as,

VIN = VL1 + VC1 + VL2 (7) while its current equation is given as,

ID1 = IL1 – IL2 (8) where,

VIN = input voltage;

VL1 = Voltage across inductor L1;

VL2 = Voltage across inductor L2;

VC1 = Voltage across Capacitor C1;

ID1 = Current through Diode D1;

IL1 = Current through inductor L1;

IL2 = Current through inductor L2.

III. SCHEME OF IMPLEMENTATION

2. Derivation of RL series circuits and RC series circuits:

The basic scheme of implementation of the proposed strategy is shown in Fig. 4. The proposed strategy consists of a PV panel as DC source, SEPIC converter as DC-DC converter for maintaining voltage stability, an inverter required for operation of BLDC motor and a BLDC motor.

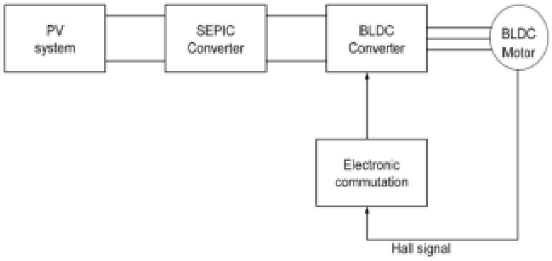

Fig. 4. Block Diagram of the Proposed Control Strategy

Schematic diagram of SEPIC converter with MOSFETs is shown in Fig. 5. The ideal switches are replaced by MOSFETs in this circuit diagram.

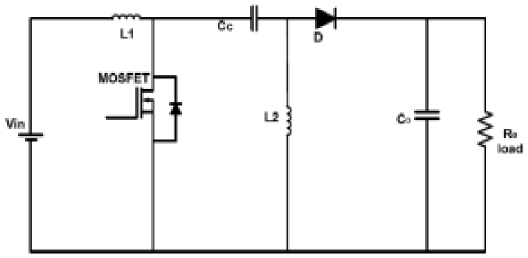

Fig. 5. Schematic Diagram of SEPIC Converter

A full schematic implementation of entire proposed strategy with programming loop is shown in Fig. 6. A 24V, 60W BLDC motor is used to indicate home appliance where this motor will be used. It is driven by a three phase inverter circuit connected to the motor at one end and SEPIC converter at the other end.

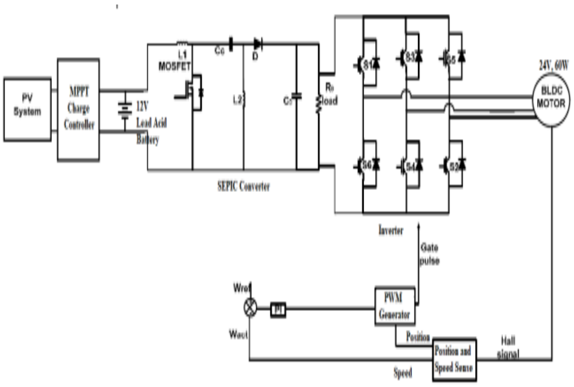

Fig. 6. Scheme of Implementation of PV connected SEPIC converter fed BLDC motor

SEPIC converter is fed by a battery source connected to solar PV panel to be able to run the BLDC motor even during night or solar blackout conditions. A Hall sensor based position feedback system is used to determine the rotor position as well as to measure the speed of the BLDC motor. A PI loop is used as a speed regulator for the control of BLDC motor.

IV. MATLAB SIMULATION AND RESULTS

Simulation study of the proposed strategy is carried out using MATLAB/Simulink 2018a. Simulink model of the proposed scheme is shown in Fig. 7.

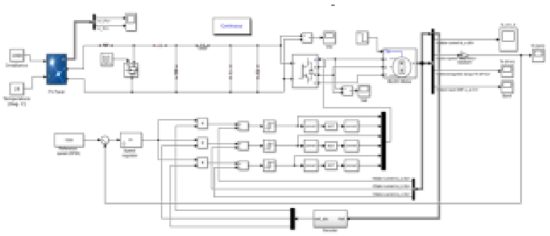

Fig. 7. MATLAB/Simulink model for PV fed SEPIC Converter based BLDC motor control

The results for 24V, 60W motor with 20W PV panel as source with SEPIC converter are demonstrated. The in and put and output voltages of SEPIC converter are shown in Fig. 8 and 9 respectively.

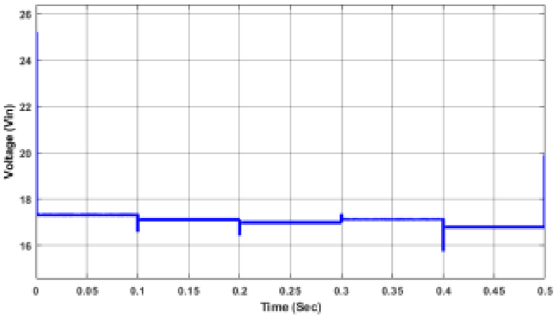

Fig. 8. Input Voltage to the SEPIC Converter

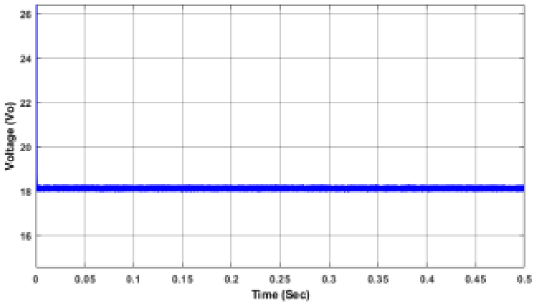

Fig. 9. Output Voltage of the SEPIC Converter

It can be observed from the Fig. 8 and 9 that output of solar PV panel is intermittent in nature while SEPIC converter output is constant irrespective of variable input to it. Initial surge is present until the large capacitors used are charged for the first time. The back-emf voltage and stator current of one phase of BLDC motor are shown in Figs. 10 and 11 respectively while Figs. 12 and 13 show its speed and torque response. It can be seen that the performance of the motor is smooth due to use of SEPIC converter.

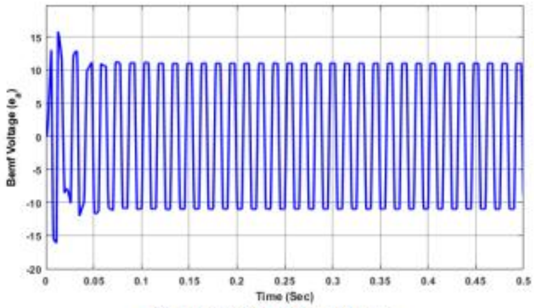

Fig. 10. Bemf Voltage of phase a

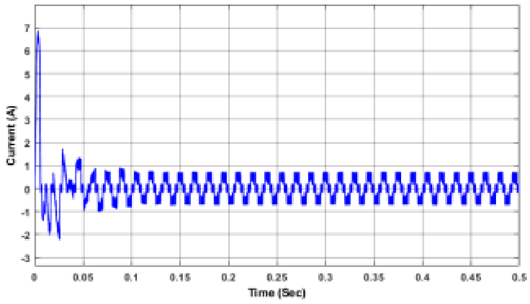

Fig. 11. Stator Current of phase a

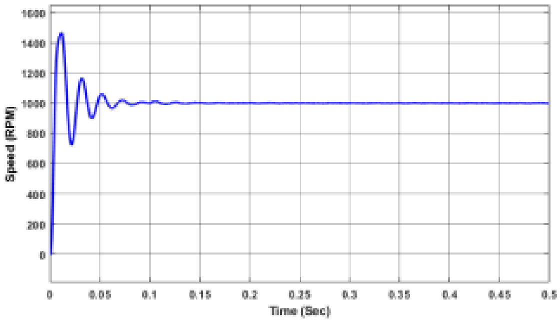

Fig. 12. Speed Response of BLDC Motor at 1000 RPM

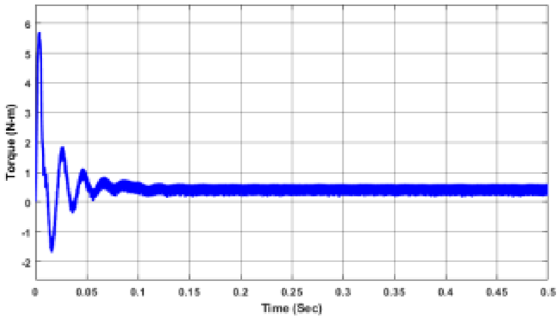

Fig. 13. Torque Response of BLDC Motor at 1000 RPM with load of 0.5 N-m

V CONCLUSION

In this paper, a PV fed SEPIC converter based BLDC motor control strategy was described. The strategy for control using PI controller was successfully implemented using MATLAB/Simulink for carrying out the simulation studies. The proposed control strategy is found to be more efficient and simpler to implement and control and has other advantages like fast dynamic performance and improved DC input-output transient performance during its operation. BLDC motor requires a reliable and highly efficient power supply for its operation and it can be concluded from the results shown in the paper that SEPIC converter is capable of handling these requirements even in unpredictable PV fed conditions.

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