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Experimental Evaluation of Solar Photovoltaic based PMBLDCM Drive for Low Power Application

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***Abstract*— This paper deals with the feasibility study of solar photovoltaic system based Permanent magnet brushless DC (PMBLDC) motor drive coupled to a low power application. The simulation model of complete drive is developed in MATLAB-SIMULINK and simulated response of proposed drive is obtained under various operating conditions. The hardware prototype setup is also developed in the lab for the validation of the simulation results. The obtained Simulation and hardware results are presented to demonstrate the feasibility of a SPV system based PMBLDCM drive.**

***Keywords*— PV Array; VSI; PMBLDCM Drive**

I. INTRODUCTION

Permanent Magnet Brushless motor is mostly used in the low power applications. It has the high efficiency rugged construction and easy of control to be used for speed control applications. Three- phase voltage source inverter (VSI) or current source inverter (CSI) is required to control the PMBLDC Motor using its rotor position information. Hall sensors are used for the rotor position sensing. These sensors increase the size, cost and complexity of PMBLDCM drives. Recently, PMBLDCM drives are used in electric vehicles (EVs) and Hybrid electric vehicles (HEVs) due to the environmental concern vehicular emissions [1-5].

At present, we have the crises of fossil fuel, conventional resources such as coal, Petroleum and Natural gas. Due to the pollution problem, Green house effect and CO_2 emission, humankind is trying to utilize the non conventional resources in an appropriate way. Advanced technologies are increasing for utilization of renewable energy in different applications.

Amongst various renewable energy sources, Solar Energy plays an important role in recent scenario. Because of the free availability of solar energy, it can be use for different applications like water heater, solar cooker, solar water pump, solar street light etc. For the electricity extraction, solar photovoltaic systems consisting of semiconductor cells, which convert the solar energy into electricity, are used in different applications. The output of SPV system depends upon the solar radiation and temperature. Maximum power point tracking (MPPT) is required for the maximum energy extraction from SPV systems. As a thrust area, researchers are trying to increase its efficiency, reliability and ease of handling [6-7].

This paper presents a standalone solar PV system based PMBLDCM drives for low power applications. The PV module supplied to VSI for driving the PMBLDC motor. The proposed system includes PV module, three phase VSI, and PMBLDCM drive. The experimental setup is implemented for the practical analysis of proposed system.

II. PROPOSED SYSTEM CONFIGURATION AND WORKING OF OPERATION

Fig. 1 shows the proposed system consisting of a SPV array, VSI and PMBLDCM drive. The Solar radiation strikes on the surface of PV array and it generate DC supply at output terminal of PV system. A three phase VSI is required to operate the PMBLDCM drive.

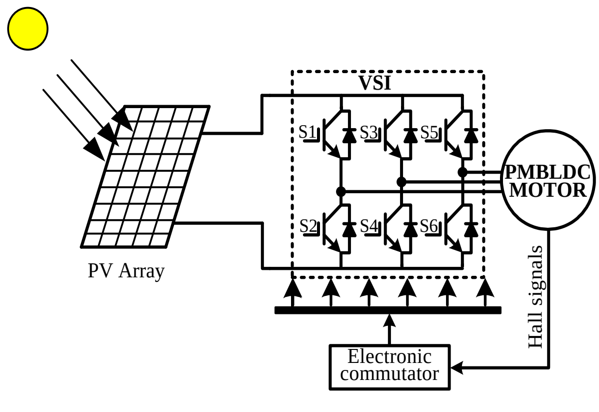

Fig.1: Solar PV based PMBLDCM drive

The Hall sensor is required for sensing the rotor position and feed it to electronic commutator. Electronic commutator generates the six gate signal for each switch of VSI so that PMBLDCM drive is operated as desired for Low Power application.

A. *Modelling of PV Module*

The equivalent circuit of a single PV cell is given in fig. 2. It consist a current source, a diode, a shunt resistance and a series resistance [7].

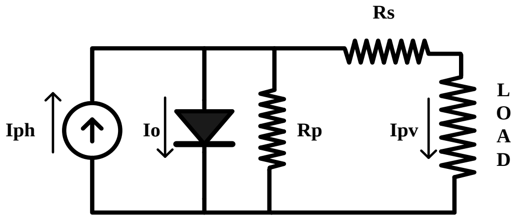

Fig.2: PV Cell circuit model

Iph is the Photon current, Rp and Rs are the shunt and series resistance respectively. The value of Rp should very high and Rs should be very low, hence they neglected to simplify the analysis. The PV module is the combinations of PV cells connected in series and parallel. For high voltage, The modules should be connect in series and high current, the connection should be in parallel.

Module Parameters and mathematical equations the PV modules are given below [8].

Table-1: PV Parameters Definition

Vpv	Output voltage of a PV module (V)
Ipv	Output current of a PV module (A)
Tr	Reference temperature (298 K)
T	Module operating temperature in Kelvin
Iph	Light generated current in a PV module (A)
Io	PV module saturation current (A)
A /B	An ideality factor (1.6)
K	Boltzmann constant (1.3805×10^{-23} J/K)
q	Charge on electron(1.6×10^{-19} C)
Rs	Series resistance of a PV module
Rp	Parallel resistance of PV module
Iscr	PV module short-circuit current at 25°C and 1000W/m^2
Ki	short-circuit current temperature co-efficient at Solar radiation 1000W/m^2
S	PV module illumination(W/m^2) = 1000W/m^2
Ego	Band gap for silicon (1.1 eV)
Ns	number of cells connected in series
Np	number of cells connected in Parallel

Module photo-current:

$$I_{ph} = [I_{scr} + K_i(T - 298)] * \frac{S}{1000} \quad (1)$$

Module reverse saturation current (I_{rs}):

$$I_{rs} = \frac{I_{scr}}{[\exp(\frac{qV_{OC}}{N_S KAT}) - 1]} \quad (2)$$

The Module Saturation current I_o:

$$I_o = I_{rs}[T/T_r]^3 \exp(\frac{qEgo}{AK} * \left\{\frac{1}{\mathrm{Tr}} - \frac{1}{\mathrm{T}}\right\}) \quad (3)$$

The output PV module current I_{pv}:

$$Ipv = Np * Iph - Np * Io \left[exp\left\{q * \frac{Vpv + IpvRs}{NsKAT}\right\} - 1\right] \quad (4)$$

B. *Modelling of PMBLDCM Drive*

The PMBLDCM drives in low power applications are mostly supplied from a DC source. The commutation of PMBLDCM is accomplished electronically by a three phase voltage source inverter (VSI) based on current control scheme in the inner loop of speed control and rotor position signal acquired using Hall Effect sensors.

The VSI Bridge feeding PMBLDCM uses insulated gate bipolar transistors (IGBTs) to reduce the switching stress.

Fig.3 shows the equivalent circuit of VSI Fed PMBLDCM Drive. The output of VSI for phase 'a' is given as

$$V_{ao} = (Vdc/2) \qquad \text{for } S_1 = 1, S_2 = 0 \quad (5)$$

$$V_{ao} = (-Vdc/2) \qquad \text{for } S_2 = 1, S_1 = 0 \quad (6)$$

$$V_{ao} = 0 \qquad \text{for } S_1 = 0, S_2 = 0 \quad (7)$$

$$V_{an} = V_{ao} - V_{no} \quad (8)$$

Where V_{ao}, V_{bo}, V_{co} and V_{no} are the 3-phase voltage and neutral point dc link voltages.

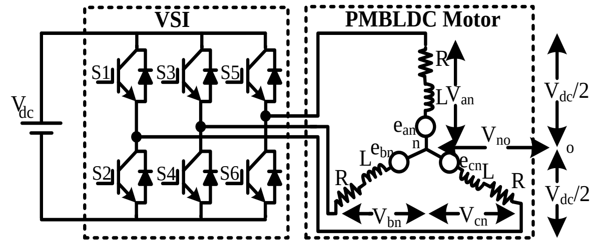

Fig.3: Equivalent circuit of VSI fed PMBLDCM Drive

The PMBLDC motor is modeled in the form of a set of differential equations [9] given as

$$V_{an} = R_a I_a + p\lambda_a + e_{an} \quad (9)$$

$$V_{bn} = R_b I_b + p\lambda_b + e_{bn} \quad (10)$$

$$V_{cn} = R_c I_c + p\lambda_c + e_{cn} \quad (11)$$

In above equations, p represents the differential operator, ia, ib, ic are currents, $\lambda_a, \lambda_b, \lambda_c$ are the flux linkages and e_{an}, e_{bn}, e_{cn} are phase to neutral back emf of PMBLDCM, in respective phases, Ra, Rb, Rc are resistances of motor windings/phase.

The Torque developed in PMBLDC motor is given as

$$T_e = (e_{an} i_a + e_{bn} i_b + e_{cn} i_c)/\omega_r \quad (12)$$

where ω_r is speed of motor in rad/sec.

III. SIMULATION AND HARDWARE IMPLEMENTATION

A. *Simulation Model of Proposed System*

The SIMULINK / MALAB is a basic tool for understanding the behavior of the system. The SIMULINK models developed in MATLAB using the mathematical equations of solar PV system to generate the DC supply. The DC link capacitor is connected to the output of the PV system terminal to maintain the voltage level. The 3 phase VSI is used to convert DC to AC for operating the drive using Electronic commutation. The parameters of motor are same as the available motor in Hardware. Fig.4 shows SIMULINK model of proposed system.

B. *Hardware Implementation of Proposed System*

The hardware setup is implemented using the PV modules; IGBTs based Voltage source inverter (VSI) and proposed drive. The PV modules are used with following parameters of single module is shown in Table2.

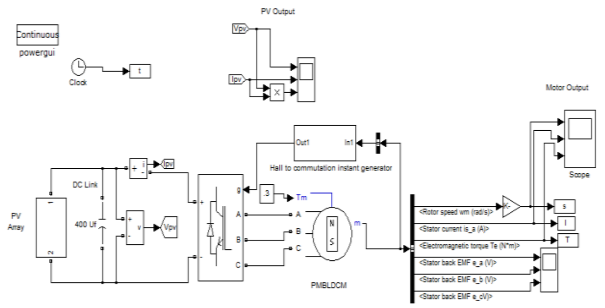

Fig.4: SIMULINK model of proposed system

Table-2: Key Specification of Single PV Module

Electrical Characteristics	ELDORA 40
Nominal Power	40 W
Optimum Operating Voltage	21.9 V
Optimum Operating current	2.45 A
Open circuit voltage Voc	17.4 V
Short circuit current Isc	2.3 A
Temperature coefficient	0.005A/^{o} C

Two modules connected in parallel for operating the proposed PMBLDCM drive. The output of the PV system is approximate 17 volts and current is less than 1 A. DC link capacitor is used for maintain the voltage level. The proposed drive is operated by the Photovoltaic system. Fig. 5 shows the hardware implementation using PV system and dSPACE signal processor.

IV. PERFORMANCE EVALUATION OF PROPOSED SYSTEM

This section deals with the results and discussion on the proposed drive. The Simulation modeled proposed system discussed in III. The Simulation results are shown in Fig. 6.

Fig.5: Hardware implementation of proposed drive

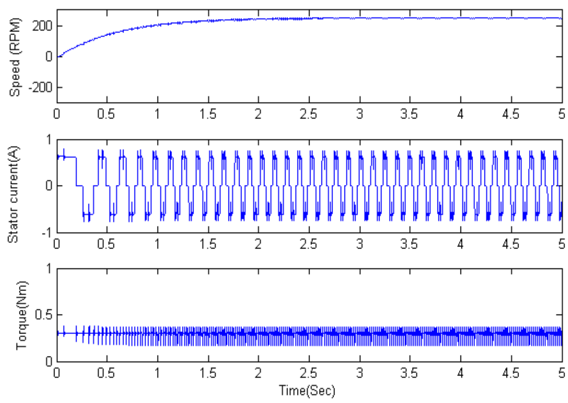

Fig.6: Simulation results of Proposed System

The details of the motor parameter mentioned in appendix. The output of the PV system around 17V, 1A and 470 µf DC link capacitor connected to the VSI. The Proposed PMBLDCM drive has constant torque 0.3 Nm and it give the speed of 250 rpm which can be used for the low power application.

The Proposed system Hardware is operated for validation the simulation results. The parameters of motor are given in appendix. The dSPACE is used for development of the hardware prototype of proposed PMBLDCM drive. Opto-isolation is provided between processor and switches used in VSI and PFC converter for protection. A filtering, isolation and driver circuit is also required for Hall Effect sensor position. Test results of proposed system are discussed in the following section.

In Hardware Implementation, ELDORA40 PV modules are used for the analysis study and validation of the Proposed PMBLDCM drive. In Fig. 7(a) and 7(b), the speed and stator current are shown and their waveform approximate same to the simulated results.

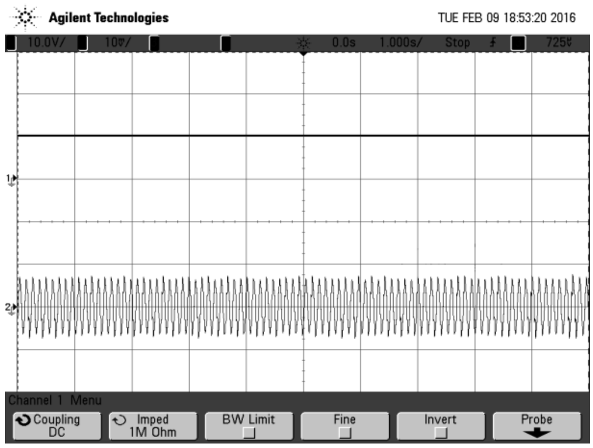

Fig.7 (a): Performance of Solar PV fed PMBLDCM Drive

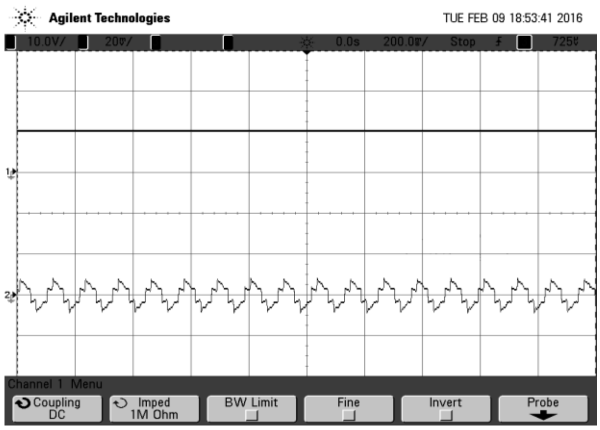

Fig.7 (b): Enlarge view of Fig. 7(a)

V. CONCLUSION

A Solar Photovoltaic based PMBLDCM Drive has been evaluated for the low power applications. The simulation results have been presented for demonstration of proposed concepts and its validation has been carried out using the

Hardware prototype. Solar PV based system is simple, reliable, conserve energy and needs no maintenance.

APPENDIX

Rated Power: 1.1 KW, rated speed: 4600 rpm, rated current 2.2 A, rated torque: 2.2 Nm, number of pole pairs:2, input DC voltage: 310 Vdc, phase to phase resistance: 3.07 Ω, phase to phase inductance: 6.57 mH, maximum current: 10.3 A, maximum torque: 6.6 Nm, Voltage constant (Kb): 0.49.

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