Controlling the Speed of Brushless DC motor fed by Solar Photovoltaic Array

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Abstract : The current trend in energy sector is the utilization of renewable energy. The renewable energy solar energy is widely used in day to day life in various application. Most of the applications such as washing machines, water pumping, fans, Blowers, Electric Vehicles and many more used BLDC motor for their operation. BLDC motor is having more advantageous features compared to other motors of same rating. This paper presents the controlling the speed of BLDC motor fed by the solar photovoltaic array.

***IndexTerms* – Brushless DC motor, commutation, solar photovoltaic array, open loop control, closed loop control.**

I. INTRODUCTION

The solar technology is gaining more popularity in the electrical energy sector as the conventional way of generating energy is insufficient to meet the growing demand. A PV cell receive the sun light in the form of photon energy and the function of PV cell to convert this photon energy into electrical energy for the applications. In other terms a PV cell is a device whose electrical characteristics (current, voltage and resistance) varies when exposed to sun light. The permanent magnet Brushless DC motor having more advantageous features compared to other related motors. The merit of BLDC motor is its higher efficiency, high operating life, high reliability, high ruggedness, easy to drive, capability to operate successfully at low voltage, better speed torque characteristic and excellent performance over a wide range of speed [1]. There are various techniques or method have been used for the speed control of BLDC motor. In this paper also speed control of BLDC motor is presented which is fed by the renewable energy i.e solar energy. The speed of the motor is controlled by varying the supplied given to the motor as per desired.

II. BRUSHLESS DC MOTOR

BLDC motor is also referred as a Permanent magnet DC synchronous motor. BLDC motor is gaining more popularity in the industrial sector due to its better performances compared to other related motors. BLDC motor is having electronically controlled commutation system unlike mechanical commutation in DC motor. It requires the rotor position information for the proper commutation of currents in the stator winding. The BLDC is a three phase motor in which the permanent magnet mounted on the rotor and has three phase stator winding in star connection. BLDC motors includes either internal or external position sensors to sense the actual rotor position, or the position can be detected without sensors.

The BLDC commutation technique is to sense the rotor position, then energize the phases to produce the most amount of torque. The rotor travels 60 electrical degrees per commutation step. The appropriate stator current path is activated when the rotor is 120 degrees from alignment with the corresponding stator magnetic field, and then deactivated when the rotor is 60 degrees from alignment, at which time the next circuit is activated and the process repeats further.

The easiest way to commutate the winding currents is by means of a position sensor. Many BLDC motor manufacturers supply motors with a three-element Hall Effect position sensor. Each sensor element outputs a digital high level for 180 electrical degrees of electrical rotation, and a low level for the other 180 electrical degrees. The three sensors are offset from each other by 60 electrical degrees so that each sensor output is in alignment with one of the electromagnetic circuits.

III. MATHEMATICAL MODELLING OF BLDC MOTOR

The BLDC motor is a three phase motor in which the permanent magnet mounted on the rotor and has three phase stator winding in star connection.

The modelling of the BLDC motor is carried out based on certain assumptions:

1. The motor is not saturated and should be operated with the rated current
2. The resistances of the three stator phase windings are equal.
3. Self-inductance and mutual inductance are constant.
4. Iron and stray losses are negligible.
5. Three phases are balanced one.
6. Uniform air gap.
7. Hysteresis and eddy current losses are not considered.

The model of the armature winding for the BLDC motor is expressed as follows:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

$v_a = stator\ phase\ voltage\ of\ phase\ a$
$v_b = stator\ phase\ voltage\ of\ phase\ b$
$v_c = stator\ phase\ voltage\ of\ phase\ c$
$R_s = stator\ resistance\ per\ phase$

$i_a = stator\ phase\ current\ of\ phase\ a$
$i_b = stator\ phase\ current\ of\ phase\ b$
$i_c = stator\ phase\ current\ of\ phase\ c$
$L_{aa} = self\ inductance\ of\ phase\ a$
$L_{bb} = self\ inductance\ of\ phase\ b$
$L_{cc} = self\ inductance\ of\ phase\ c$
$L_{ab} = mutual\ inductance\ between\ phase\ a\ and\ phase\ b$
$L_{bc} = mutual\ inductance\ between\ phase\ b\ and\ phase\ c$
$L_{ca} = mutual\ inductance\ between\ phase\ c\ and\ phase\ a$
e_a, e_b, e_c = phase back emf

Based on above mentioned assumptions, the self-inductances and mutual inductances is given below.

$$L_{aa} = L_{bb} = L_{cc} = L \quad (2)$$

$$L_{ab} = L_{bc} = L_{ca} = L_{ba} = L_{cb} = L_{ac} = M \quad (3)$$

Substituting the above equations in modeling equation.

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (4)$$

IV. Speed Control of BLDC motor

There are two ways of controlling the speed of the BLDC motor in general. One is open loop control and another one is closed loop control method. The open loop speed control is achieved by controlling the applied voltage to the stator winding of the motor whereas the closed loop speed control is achieved by controlling the applied voltage through the speed feedback from the motor. Thus the applied voltage is controlled depending on the error signal. There are other methods of speed controlling a follow:

1. Sensors based control method:

Most of the BLDC motors have three Hall sensors inside the stator on the non-driving end of the motor. Whenever the rotor magnetic poles pass near the Hall sensors they give a high or low signal indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined.[2]

2. Sensorless based control method:

In this method six discrete rotor position information in trapezoidal electromotive force (EMF) is require for the inverter operation. These are typically generated by Hall- effect switch sensors placed within the motor. There is a drawback of these sensors. They increase the cost of the motor and need special mechanical arrangements to be mounted. Hall sensors are temperature sensitive, and hence limit the operation of the motor. Therefore, the reliability is affected due to extra components and wiring connection. [3]

V. Hardware Implementation of the proposed system

This paper present the hardware implementation of the speed control of BLDC motor fed by solar photovoltaic array. This system is based on the closed loop control method for controlling the speed.

Fig.1 & Fig.2 shows the block diagram of the proposed system and accordingly the hardware implementation of the proposed system and the complete hardware model of the system shown in Fig.3.

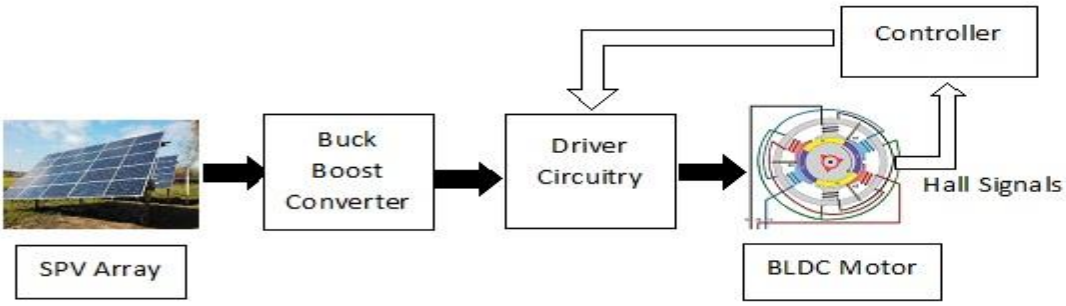

Figure 1 Block Diagram of the proposed system

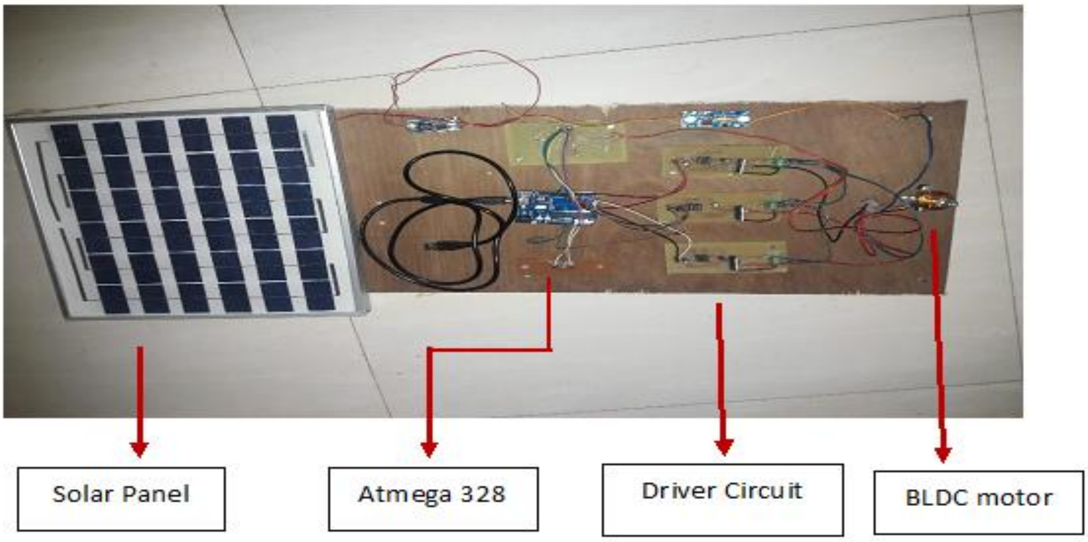

Figure 2 Hardware implementation of the proposed system along with its components

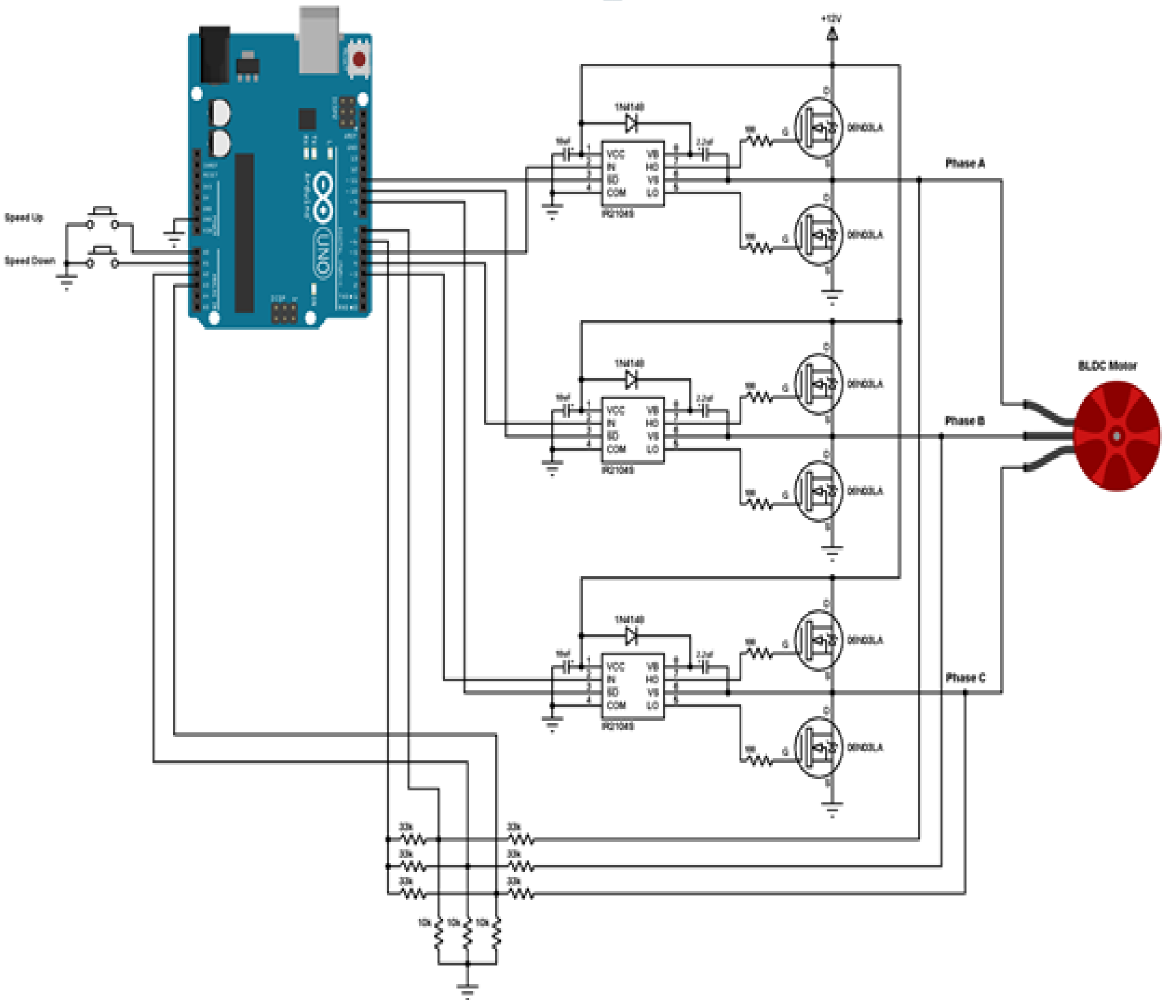

Figure 3 Circuit Diagram of the SPV array fed BLDC motor controlling system

Fig.3 shows the Circuit diagram of the SPV array fed BLDC motor controlling system, it represent the driving circuitry of the BLDC motor, the electricity generated from the SPV array along with buck boost converter is fed to the microcontroller Atmega328. From the microcontroller, the BLDC motor is driven by the driver circuitry.

In the SPV array fed BLDC system, two push buttons are used. One is used to increase the speed of the motor and another one is used to decrease the speed of the motor. All grounded terminals are connected together.

BLDC motor is a 3 phase motor. Each phase is accompanied with two N- type Mosfets, one is connected is connected on high side (+12V) and another is connected on low side (ground or 0V). The IR2104S chips are used to control high side and low side mosfets of each phase. The switching between the high side and the low side is done according to the control lines IN and SD.

IV. EXPERIMENTAL RESULTS

The driver circuit is an IR2104S IC. It is connected to each phase. It is associated with two MOSFET, one is at high side and another is at low side. The output at HO and LO depends upon the input IN and SD'. The input and output relation of IR2104S is given below.
If SD'=High (=1) then HO= IN and LO= HO' and
If SD' = Low (=0) then HO = LO = Low (=0)
The above condition is reflected in the table 6.1 given below and the fig 6.1 is the representation of the table 1

Table 6.1 Input and Output of IR2104S

IN	SD'	HO	LO
0	1	0	1
1	1	1	0
1	0	0	0
0	0	0	0

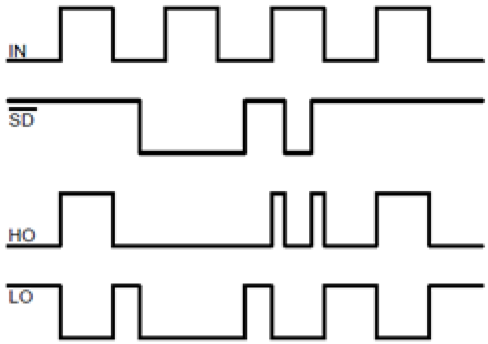

Figure 4 Input/Output timing diagram

The hall sensor code is observed in the table 2, depending upon the coding the states of each phase is observed. For every 60° rotation, one of the Hall sensors changes its state; Here each step is termed as 60° rotation. With each step, there is one motor terminal driven high, another motor terminal driven low, with the third one left floating. The relation between the sensor code and the states of each phase is shown in the table 6.2. Here f is the floating state.

Table 2 States of each Phase proportional to respective sensor code

	1	2	3	4	5	6
Code	101	001	011	010	110	100
Phase A	1	1	F	0	0	F
Phase B	0	f	1	1	f	0
Phase C	F	0	0	F	1	1

The operating states of the BLDC motor represented in table 2 is achieved by the input and output relation of driver for phase A, B and C respectively is represented in Table 3.

Table 3 Input and Output relation of gate driver IC for Phase A, Phase B and Phase C

Phase A				Phase B				Phase C			
IN	SD'	HO	LO	IN	SD'	HO	LO	IN	SD'	HO	LO
1	1	1	0	0	1	0	1	0	1	0	1
1	1	1	0	0	0	0	0	0	0	0	0
0	0	0	0	1	1	1	0	1	1	1	0
0	1	0	1	1	1	1	0	1	1	1	0
0	1	0	1	0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	1	0	1	0	1

V. CONCLUSION

This paper presented a controlling the speed of the BLDC motor using the closed loop control method with the desired results. This is a simple and efficient way of controlling the speed. The sensor based BLDC motor is considered for the controlling the speed. This system is applicable for the small applications. The further modification is also possible by using artificial intelligence techniques for controlling.

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