Modeling and Simulation of BLDC Motor Using Soft Computing Techniques

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Abstract— In this paper a soft computing technique PSIM is used for the performance simulation of the BLDC motor. With the help of its user friendly approach and some basic theories, the corresponding PSIM models for the BLDC can easily be constructed. The simulation results of BLDC motor performance can critically evaluate under various input parameters in the PSIM environment. The accuracy of this approach can also be verified by comparing the simulation results in PSIM with the response obtained from the BLDC motor established results.

Index Terms— PMBLDC, PSIM, Simulation, Soft computing, Modeling.

I. INTRODUCTION

The permanent magnet brushless dc (BLDC) motor is gaining popularity being used in computer, aerospace, military, automotive, industrial and household products because of its high torque, compactness, and high efficiency. The BLDC motor is inherently electronically controlled and requires rotor position information for proper commutations of current. The brushless DC (BLDC) motor has been used in many applications such as computer, automatic office machine, robots for automation [1], drives of many electronics and miniature machine [2]. The BLDC motor has advantages of the DC motor such as simple control, high torque, high efficiency and compactness. Also, brush maintenance is no longer required, and many problems resulting from mechanical wear of brushes and commutators are improved by changing the position of rotor and stator in DC motor. To alternate the function of brushes and commutator, the BLDC motor requires an inverter and a position sensor that detects rotor position for proper commutation of current. The typical circuit diagram of BLDC motor with converter is shown in figure 1.
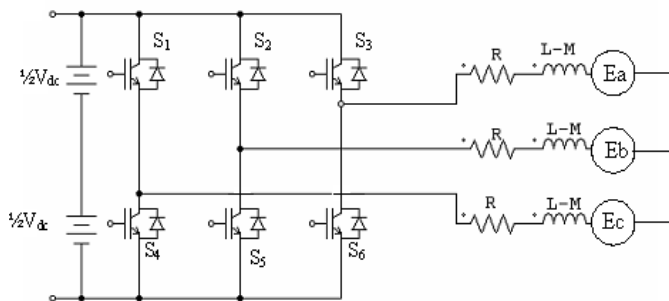

Figure – 1 BLDC motor with Converter circuit

PSIM is a simulation package specifically designed for power electronics and motor controls with fast simulation and user friendly interface. It provides a powerful simulation environment for power electronics, analog and digital control, magnetic, and motor drive system studies. In addition, PSIM supports links to third-party software like MATLAB through custom DLL blocks.

The PSIM simulation package consists of the circuit schematic program PSIM, the simulator engine, and the waveform processing program SIMVIEW. The simulation process is shown in figure -2.

II. PRINCIPLE AND CONSTRUCTION

BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and the magnetic field generated by the rotor rotates at the same frequency. BLDC motors do not experience the "slip" that is normally seen in induction motors. BLDC motors come in single-phase, 2-phase and 3-phase configurations. Corresponding to its type, the stator has the same number of windings. The 3-phase motors are the most popular and widely used [9].
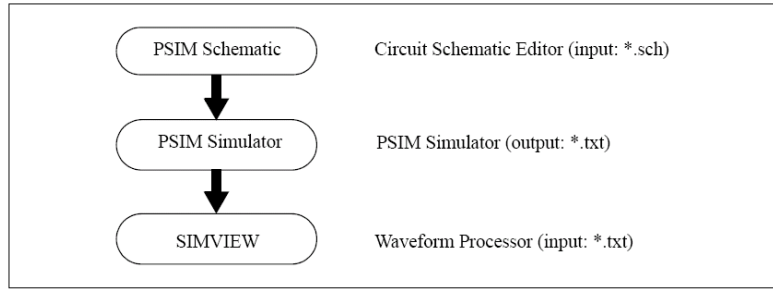
Fig. 2. PSIM Simulation process

A. Stator

The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery traditionally, the stator resembles that of an induction motor; however, the windings are distributed in a different manner as shown in figure 3. Most BLDC motors have three stator windings connected in star fashion. One or more coils are placed in the slots and they are interconnected to make a winding. Each of these windings is distributed over the stator periphery to form an even numbers of poles. There are two types of stator windings variants: trapezoidal and sinusoidal motors. This differentiation is made on the basis of the interconnection of coils in the stator windings to give the different types of back Electromotive Force (EMF).

B. Rotor

Fig. 3 - BLDC Motor Stator

The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles. Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor. Ferrite magnets are traditionally used to make permanent magnets. As the technology advances, rare earth alloy magnets are gaining popularity. The ferrite magnets are less expensive but they have the disadvantage of low flux density for a given volume. In contrast, the alloy material has high magnetic density per volume and enables the rotor to compress further for the same torque. Also, these alloy magnets improve the size-to-weight ratio and give higher torque for the same size motor using ferrite magnets. Some rotor constructions are shown in figure 4.
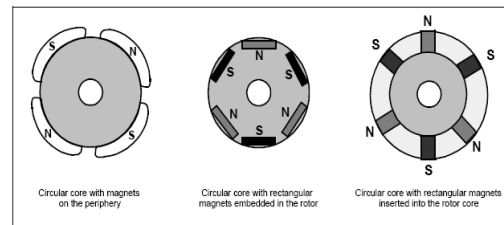

Figure 4 - Rotor constructions

C. Rotor Position Sensing

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. Rotor position is sensed by Hall Effect sensors embedded into the stator which gives the sequence of phase energisation [3]. Most of BLDC motors have three Hall sensors embedded into 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 [4, 5].

III. MATHEMATICAL MODELING

Each active phase in ac motor is describe by a first order differential equation. The general voltage equation of one of active phases is given by,

$$v_x = Ri_x + \sum_{k=1}^{n} \frac{d\psi_{kx}(\theta, i_x)}{dt}$$

Where v_x is the active phase voltage, R is the phase resistance, i_x is the phase current, θ is the rotor position, $\psi_{kx}(\theta, i_x)$ is the total flux linkage of the active phase and n is the number of phases. [6,7]. The electrical equivalent circuit of BLDC motor is shown in figure 5.

The equations of the 3-phase brushless dc machine are:

$$v_a = R \cdot i_a + (L-M) \cdot \frac{di_a}{dt} + E_a$$

$$v_b = R \cdot i_b + (L-M) \cdot \frac{di_b}{dt} + E_b$$

$$v_c = R \cdot i_c + (L-M) \cdot \frac{di_c}{dt} + E_c$$

where v_a, v_b, and v_c are the phase voltages, i_a, i_b, and i_c are the phase currents, R, L, and M are the stator phase resistance, self inductance, and mutual inductance, and E_a, E_b and E_c are the back emf of Phase A, B, and C, respectively. The back emf voltages are a function of the rotor mechanical speed ω_m and the rotor electrical angle θ_r, that is:

$$E_a = k_{e\_a} \cdot \omega_m$$

$$E_b = k_{e\_b} \cdot \omega_m$$

$$E_c = k_{e\_c} \cdot \omega_m$$

The coefficients k_{e_a}, k_{e_b}, and k_{e_c} are dependent on the rotor angle θ_r. In this model, an ideal trapezoidal waveform profile is assumed.

The mechanical equations are:

$$J \cdot \frac{d\omega_m}{dt} = T_{em} - B \cdot \omega_m - T_{load}$$

$$\frac{d\theta_r}{dt} = \frac{P}{2} \cdot \omega_m$$

where B is a coefficient, T_{load} is the load torque, and P is the no. of poles. The coefficient B is calculated from the moment of inertia J and the mechanical time constant τmech as below:

$$B = \frac{J}{\tau_{mech}}$$

IV. SIMULATION OF BLDC IN PSIM

A 3-phase brushless dc motor is taken in PSim for simulation purpose with trapezoidal waveform back emf. In figure 5, nodes a, b, and c are the stator winding terminals for Phase A, B, and C, respectively. The stator windings are Y connected, and Node n is the neutral point. The shaft node is the connecting terminal for the mechanical shaft. They are all power nodes and should be connected to the power circuit. Node sa, sb, and sc are the outputs of the built-in 6-pulse hall effect position sensors for Phase A, B, and C, respectively. The sensor output is a bipolar commutation pulse (1, 0,and -1). The sensor
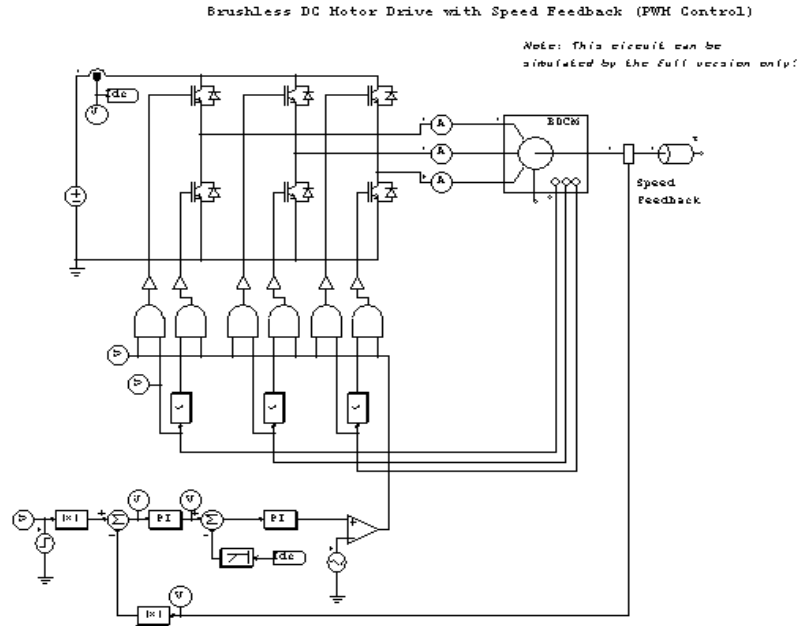

Fig. 5 - Simulation model of BLDC

output nodes are all control nodes and should be connected to the control circuit [8].

A hall effect position sensor consists of a set of hall switches and a set of trigger magnets. The hall switch is a semiconductor switch (e.g. MOSFET or BJT) that opens or closes when the magnetic field is higher or lower than a certain threshold value. It is based on the hall effect, which generates an emf proportional to the flux-density when the switch is carrying a current supplied by an external source. It is common to detect the emf using a signal conditioning circuit integrated with the hall switch or mounted very closely to it. This provides a TTL-compatible pulse with sharp edges and high noise immunity for connection to the controller via a screened cable. For a three-phase brushless dc motor, three hall switches are spaced 120 electrical deg. apart and are mounted on the stator frame. The set of trigger magnets can be a separate set of magnets, or it can use the rotor magnets of the brushless motor. If the trigger magnets are separate, they should have the matched pole spacing (with respect to the rotor magnets), and should be mounted on the shaft in close proximity to the hall switches. If the trigger magnets use the rotor magnets of the machine, the hall switches must be mounted close enough to the rotor magnets, where they can be energized by the leakage flux at the appropriate rotor positions.

The figure 4 shows a brushless dc motor drive system with speed feedback. The motor is fed by a 3-phase voltage source inverter. The outputs of the motor hall effect position sensors are used as the gatings signals for the inverter, resulting a 6-pulse operation. The speed control is achieved by modulating sensor commutation pulses (Vgs for Phase *A* in this case) with another high-frequency pulses (Vgfb for Phase *A*). The high-frequency pulse is generated from a dc current feedback loop. The DC voltage is applied to the BLDC motor which is converted into three phase AC by use of inverter. The three phase inverter circuit consists of six IGBT's which converts DC to AC .Three current probes are connected through each phase to obtain the wave form of the current in each phase. The outputs of the motor Hall Effect position sensors are used as the gatings signals for the inverter's IGBT's.

The table – 1 mentioned parameter of the BLDC motor [8].

Table - 1: BLDC MOTOR PARAMETER

R(stator resistance) in ohms	11.9
L(stator self inductance) in H	0.00207
M(stator mutual inductance) in H	0.00069
V_{pk}/K_{rpm}	32.3
$Vrpm/K_{rpm}$	22.9
No. of poles P	4
Moment of Inertia in Kg m^2	7E-006
Mech. Time constant in sec.	0.006

Theta_0(deg.)	0
Theta_advance(deg.)	0
Conduction Pulse Width in degree	120
Voltage rating in volts	300
Current rating in A	10
Power rating in watts	3000
Speed rating in rpm	10000

The simulation process have three steps as shown in figure 2. Complete simulation model of BLDC Motor with converter and control circuit is shown in figure 5. Simulation Model is consists of BLDC motor, six IGBT's, current probes, speed sensor, AND gates, Proportional Blocks, voltage probes (node to ground), comparator, Proportional-Integral Controller, 2nd order low pass filter etc.

V. RESULTS

These results were obtain by running the SIMVIEW. The results of other parameters like gate pulse, Hall Effect sensor pulses also can be obtained by adding these parameters in SIMVIEW. The simulation waveforms show the start-up transient of the mechanical speed (in rpm), developed torque *Tem*, and 3-phase input currents.

The simulation is take place at reference speed of 7000 rpm and 0.25 Nm load torque and a DC voltage of 300V. The result is shown in the **figure 6**, the speed starts from 0rpm, it decreases upto t=2ms and starts increasing slowly. It increases upto 6500rpm at time t=8ms and then it becomes constant at 6500rpm at t=8ms. The speed always remains less than the reference speed of 7000rpm. Therefore there is a error in speed of 500rpm with respect to reference speed. Starting torque is almost 2.75 Nm. Motor attains a constant torque of 1Nm at 5 ms.

The simulation is take place at reference speed of 7000 rpm and 0.01 Nm load torque and a DC voltage of 300V. As shown in the **figure 7,** the speed starts from 0 rpm ,it decreases upto t=2ms and starts increasing slowly. It increases upto 7000 rpm at time t=8ms and then it becomes constant at 7000 rpm at t=8ms.The speed remains the same as than of the reference speed of 7000 rpm. Therefore there is no error in speed with respect to reference speed.Starting torque is almost 2.65 Nm. Motor attains a constant torque of 0.75 Nm at 5 ms.

The simulation is take place at reference speed of 400 rpm and 0.25 Nm load torque and a DC voltage of 300V. As shown in the **figure 8**, the speed starts from 0 rpm, it decreases upto t=20ms and there after becomes nearly constant -2000 rpm in simulation result. Switching torque is almost 0.89 Nm. At t=5ms the torque becomes 0.As the speed is negative and the torque is becoming zero so the motor do not start.
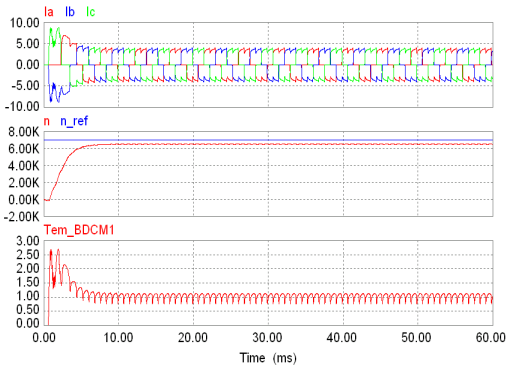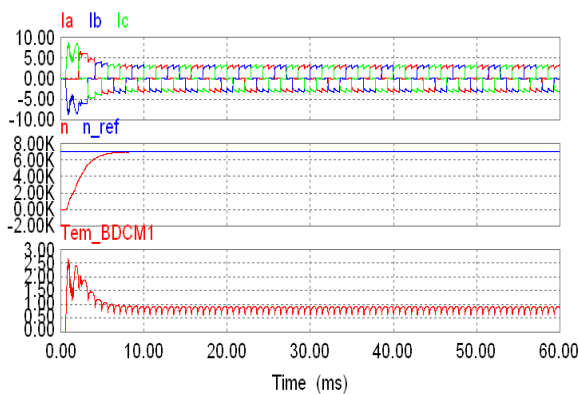
Figure 6 - speed 7000 rpm & load torque 0.25 Nm

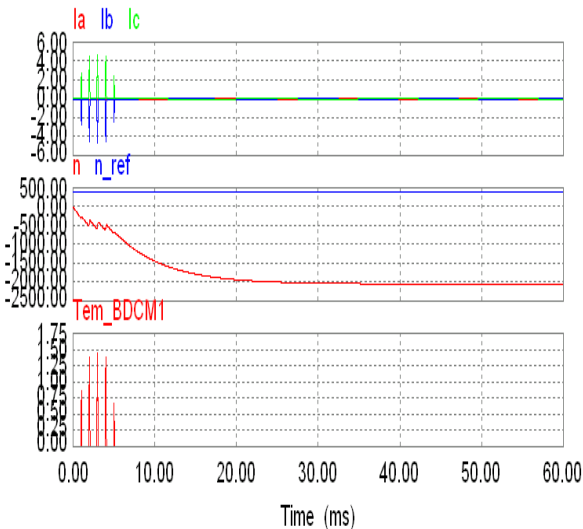Figure7 - Results at 7000 rpm & 0.01 Nm

Figure 8 - Results at 400 rpm & 0.25 Nm

VI. CONCLUSION

PSim software is designed to provide a debugging, diagnostic and demonstration tool for the development of algorithms and applications in electric drives. The modeling and analysis of BLDC is done for Psim The simulation results of this paper has proposed the use of a commercially available software package to study the performance of BLDC motor. The PSIM simulation provides good soft computing technique. The results of simulation model gives help in building hardware with expected results. The simulation saves time and manpower in making hardware models at initial stages and reduces the costing of the research work.

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