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Modeling and Simulation of A Bldc Motor By Using Matlab/Simulation Tool

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ABSTRACT: *The objective of this research to study the Modeling and simulation of BLDC motor by using MATLAB as tool. This research explores the performance of a three-phase permanent magnet (PM) motor operating as a brushless DC (BLDC) motor is discussed. When the permanent Magnet Motor supplied with frequency changes according to the actual rotor speed, it means the speed signal is fed back to the controller, which generates the appropriate frequency to supply the stator winding. This research carried out Modeling of the PM 3-phase synchronous and PM 3-phase brushless DC motors in dynamic and steady-state conditions.*

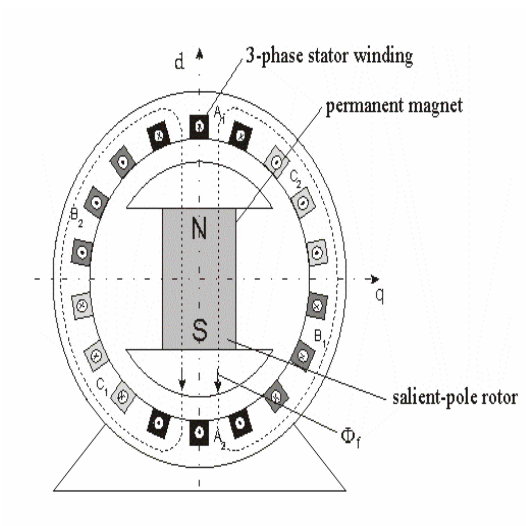
I. INTRODUCTION:

Brushless Direct Current (BLDC) motors are one of the motor types rapidly gaining popularity. BLDC motors are used in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation.

1. a. CONSTRUCTION

AC permanent magnet (PM) motors can perform as can perform as brushless DC motor,the motor consists of a wound stator and a rotor. The stator may have a single-phase or multi-phase winding which is sometimes called the armature winding (Fig. 1.1). The rotor just has permanent magnets. There are two types of rotors.

- Salient-pole rotor (Fig. 1.1) – mostly for low-speed machines.
- Cylindrical rotor (Fig. 1.2) – usually for high-speed machines.



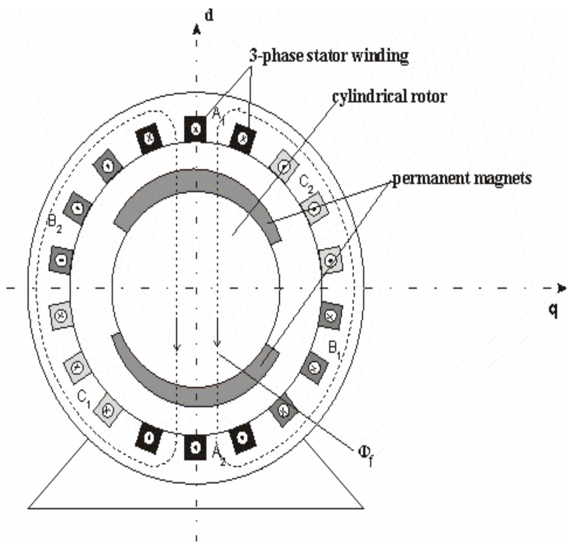


Fig. (1.1) Salient-pole rotor Fig. (1.2)Cylindrical rotor

In both cases, the PM can be attached to the rotor surface (Fig. 1.2) or it can be buried. (Fig. 1.1) Since there is no winding in the rotor, the AC PM machines are also called brushless PM machines. The rotor of the AC PM motor rotates synchronously with the magnetic field generated by the stator1winding. At the motor start-up, the rotor has zero speed. Due to its high inertia, it cannot instantaneously shoot to its synchronous speed. However, this can happen if we supply the stator winding with frequency, rising gradually from 0 to its rated value. To do this,

The motor has to be supplied from a variable frequency inverter.

The frequency can be controlled by imposing the desired reference frequency or the motor itself can set an appropriate frequency value required for its actual speed. If its operating with "self-controlled frequency" as explained in the latter mode above, then this operation is that of a brushless DC motor. (Fig.1.3)

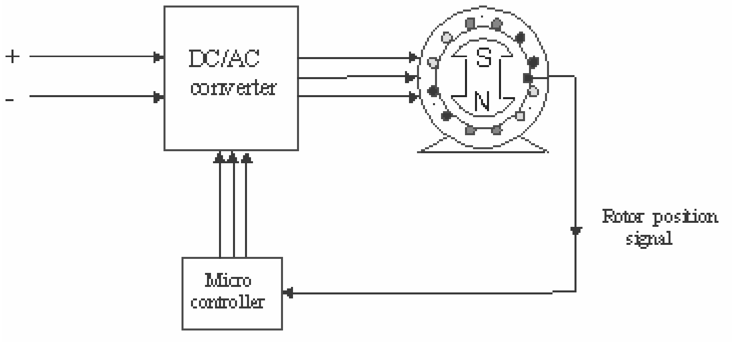


Fig. (1.3) Supply circuit scheme of brushless DC PM Motor

II. DYNAMICS OF THE BLDC MOTOR

2.1DYNAMIC MODEL OF THE BLDC MOTOR

It is assumed that the BLDC motor is connected to the output of the inverter, while the inverter input terminals are connected to a constant supply voltage, as was shown in Fig.2.1.The equivalent circuit model that refers to this circuit diagram is shown in Fig. 2.2.Another assumption is that there are no power losses in the inverter and the 3-phase motor winding is connected in star.

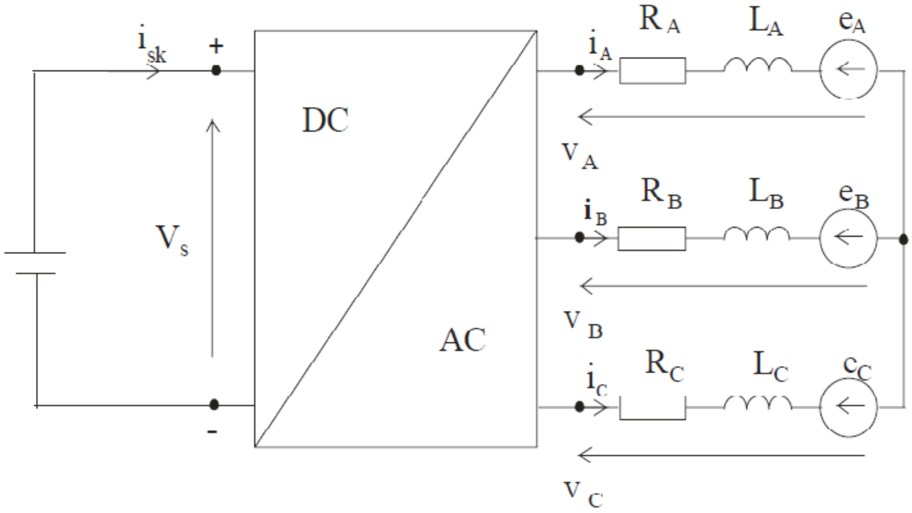


Fig. 2.1 Equivalent circuit of 3-phase PM BLDC motor

III. THE EQUATIONS THAT GOVERN FOR MODEL

$$V_A = V_N + V_{sA}$$
$$V_B = V_N + V_{sB} \qquad \textbf{3.2}$$
$$V_C = V_N + V_{sC}$$

Where
vsA, *vsB*, *vsC* are the inverter output voltages that supply the 3 – phase winding.
vA, *vB*, *vC* are the voltages across the motor armature winding.
vN – voltage at the neutral point

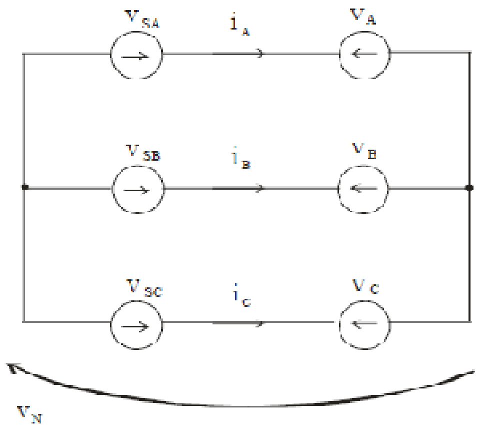


Fig. 2.2 Schematic representation of equation 3.2

For a symmetrical winding and balanced system, the voltage equation across the motor Winding is as follows:

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} R_A & 0 & 0 \\ 0 & R_B & 0 \\ 0 & 0 & R_C \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L_A & L_{AB} & L_{AC} \\ L_{BA} & L_B & L_{BC} \\ L_{CA} & L_{CB} & L_C \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} e_A \\ e_B \\ e_C \end{bmatrix} \qquad \textbf{3.3}$$

Or in the shortened version representing the vector

$$V_a = R_a . I_a + \frac{d}{dt} L_a I_a + E_a \qquad \textbf{3.4}$$

Since RA = RB = RC =Ra, the resistance takes the following vector form:

$$R_a = \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_a & 0 \\ 0 & 0 & R_a \end{bmatrix} \qquad \textbf{3.5}$$

As for the inductances, since the self and mutual inductances are constant for surface mounted permanent magnets on the cylindrical rotor and the winding is symmetrical:

$$L_A = L_B = L_C = L \ and \ L_{AB} = L_{AB} = L_{BC} = L_{CA} = L_{BA} = L_{AC} = L_{CB} = M \qquad \textbf{3.6}$$

Hence the inductance takes the form

$$L_a = \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \qquad \textbf{3.7}$$

For a Y-connected stator winding,

$$i_A + i_B + i_C = 0 \qquad \textbf{3.8}$$

Therefore, the voltage takes the following form

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} R_A & 0 & 0 \\ 0 & R_B & 0 \\ 0 & 0 & R_C \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L_s & 0 & 0 \\ 0 & L_s & 0 \\ 0 & 0 & L_s \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} e_A \\ e_B \\ e_C \end{bmatrix} \qquad \textbf{3.9}$$

Where the synchronous inductance, *Ls*= *L* –*M*

The angle between a particular phase and the rotor, at any given time, is called θ_e. Fig. 2.3 illustrates the position of this angle, with respect to phase A for example. Since phase A is chosen as the reference, the electromotive forces written in the form of a matrix, ***Ea*** take the form:

$$E_a = \frac{K_E}{p}\begin{bmatrix} \sin\theta e \\ \sin\left(\theta e - \frac{2}{3}\pi\right) \\ \sin(\theta e - \frac{4}{3}\pi) \end{bmatrix}\frac{d\theta e}{dt} \qquad \textbf{3.10}$$

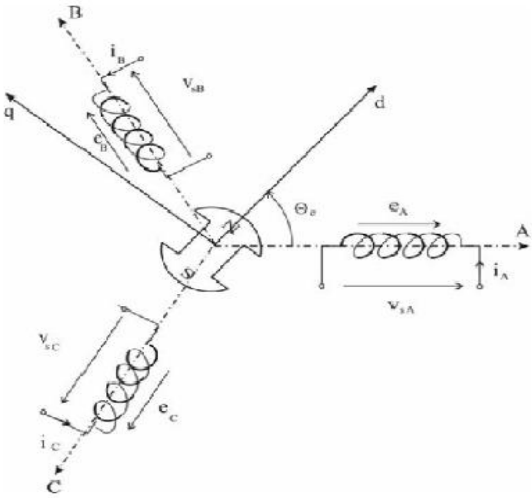


Fig. 2.3 Rotor position angle (θe)

To link the input voltages and currents of the inverter with those of the output, the power equality equation, Pin = Pout is assumed at both sides, from this, the inverter input current is:

From this, the inverter input current is:

$$i_{sk} = \frac{1}{V_s}(i_A v_{sA} + i_B v_{sB} + i_C v_{sC}) \qquad \textbf{3.11}$$

Where, v_{sA} *vsB* and *vsC* are the phase voltages that supply the motor

$$T_{em} = J_{eq}\frac{d_{\omega m}}{dt} + B\omega m + T_L \qquad \textbf{3.12}$$

where is the equivalent moment of inertia, and J_{eq} = J_M+ J_L is the equivalent moment of inertia, and J_M ,JL are the moment of inertia of the motor and load respectively, B-friction coefficient and TL-load torque.

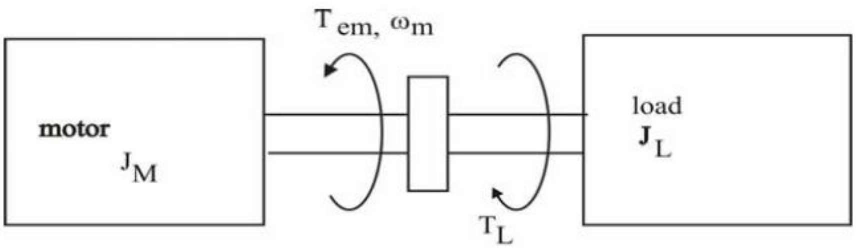


Fig. 2.4 Scheme Mechanical System

The electromagnetic torque for this 3-phase motor is dependent on the current (i), speed (ω_m) and electromotive force (e). The equation is:

$$T_{em} = \frac{e_A i_A}{\omega_m} + \frac{e_B e_b}{\omega_m} + \frac{e_C e_c}{\omega_m} = K_E(f_a(\phi e).i_A + f_b(\phi e).i_B + f_c(\phi e).i_C \qquad \textbf{3.13}$$

where,

$$f_a(\phi e) = \sin\theta e$$
$$f_b(\phi e) = \sin\left(\theta e - \frac{2}{3}\pi\right)$$
$$f_c(\phi e) = \sin(\theta e - \tfrac{4}{3}\pi)$$

Combining all the above equations, the system in state-space form is;

$$x = Ax + Bu$$

$$x = [i_A \;\; i_B \;\; i_C \;\; \omega_r \;\; \theta e]^t \qquad \textbf{3.14}$$

$$A = \begin{bmatrix} -\frac{R_s}{L_s} & 0 & 0 & -\frac{K_E(f_a(\phi_e))}{L_s} & 0 \\ 0 & -\frac{R_s}{L_s} & 0 & -\frac{K_E(f_b(\phi_e))}{L_s} & 0 \\ 0 & 0 & -\frac{R_s}{L_s} & -\frac{K_E(f_c(\phi_e))}{L_s} & 0 \\ \frac{K_E(f_a(\phi_e))}{J} & \frac{K_E(f_b(\phi_e))}{J} & \frac{K_E(f_c(\phi_e))}{J} & -\frac{D}{J} & 0 \\ 0 & 0 & 0 & \frac{P}{2} & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{1}{L_s} & 0 & 0 & 0 \\ 0 & \frac{1}{L_s} & 0 & 0 \\ 0 & 0 & \frac{1}{L_s} & 0 \\ 0 & 0 & 0 & -\frac{1}{J} \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$u = [v_A \; v_B \; v_C \; T_L]^t$$

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IV. SIMULATION OF MOTOR DYNAMICS

The simulation of the BLDC motor was done using the software package MATLAB/SIMULINK. For this purpose, the motor's block diagram was constructed, as shown in Fig.4.1. After running the simulation, the speed, torque, current, input and output power waveforms were recorded and analyzed. The inverter was supplied with a voltage of 42V DC and the motor loaded with a rated torque of 0.56 N·m. Phase A voltage is a square wave of 21V DC. However, notice how the phase current is distorted from the square wave shape to something between a sine-wave and a square wave. This is a result of the inductance effect. After the initial start-up, the speed oscillates around 377 rad/s. As expected, the load torque is a constant straight line of 0.56 N·m. The electromagnetic torque depends on phase currents, constant K, speed and electromotive force. Therefore; all these quantities affect the appearance of its waveform. After the start-up process, the motor reaches steady-state at around 0.016 seconds. The efficiency of motor can be calculated as follows.

4.1. ELECTRICAL AND MECHANICAL SPECIFICATION OF THE MOTOR

Motor Type	10 pole 3-phase BLDC
Rated Voltage	42 V DC
Rated Speed	3600 RPM
Rated Power	210 Watts
Rated Current	7A (rms)/Ph

Table: 4.1 Data of Motor

Per Phase Resistance R_{ph}	0.077 ohms
Supply voltage V_s	42 V DC
Per Phase Reactance X_{ph}	0.396 ohms
Per Phase Inductance L_{ph}	0.210 mH
Moment of Inertia J_{eq}	7.895×10^{-7} Kg m^2
Constant K_E	0.073 V.s/rad
Rated Loaded Torque T_L	0.56 N.m
Frequency	60 Hz

Table: 4.2.Electrical and Mechanical specification of the motor

4.2. BLOCK CIRCUIT DIAGRAM OF BLDC MOTOR FOR SYSTEM AND SUBSYSTEM

The circuit and block diagram as shown below, the system and subsystem of BLDC motor with circuit used for run the motor with the rated supply voltage.

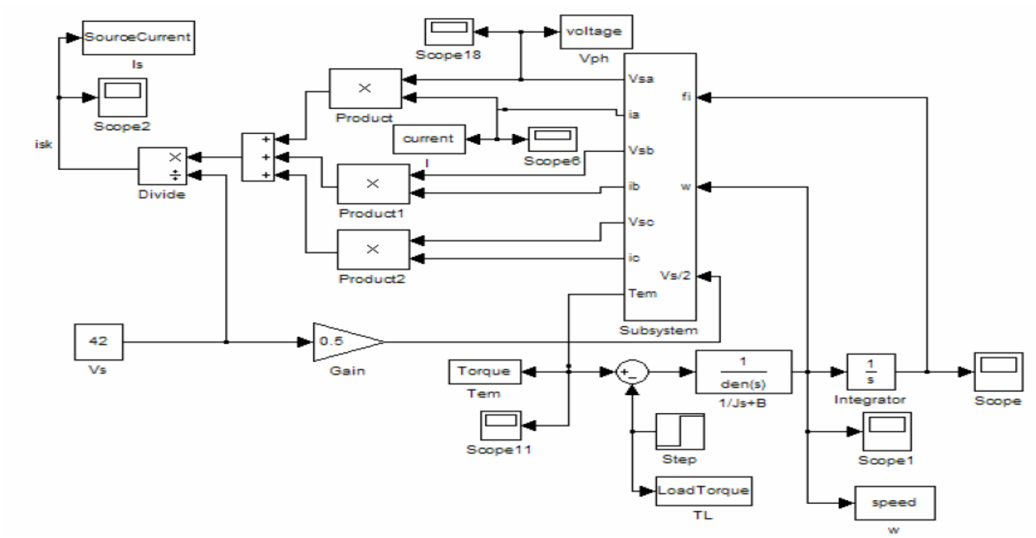


Fig: 4.1.Block Diagram of BLDC Motor Operation

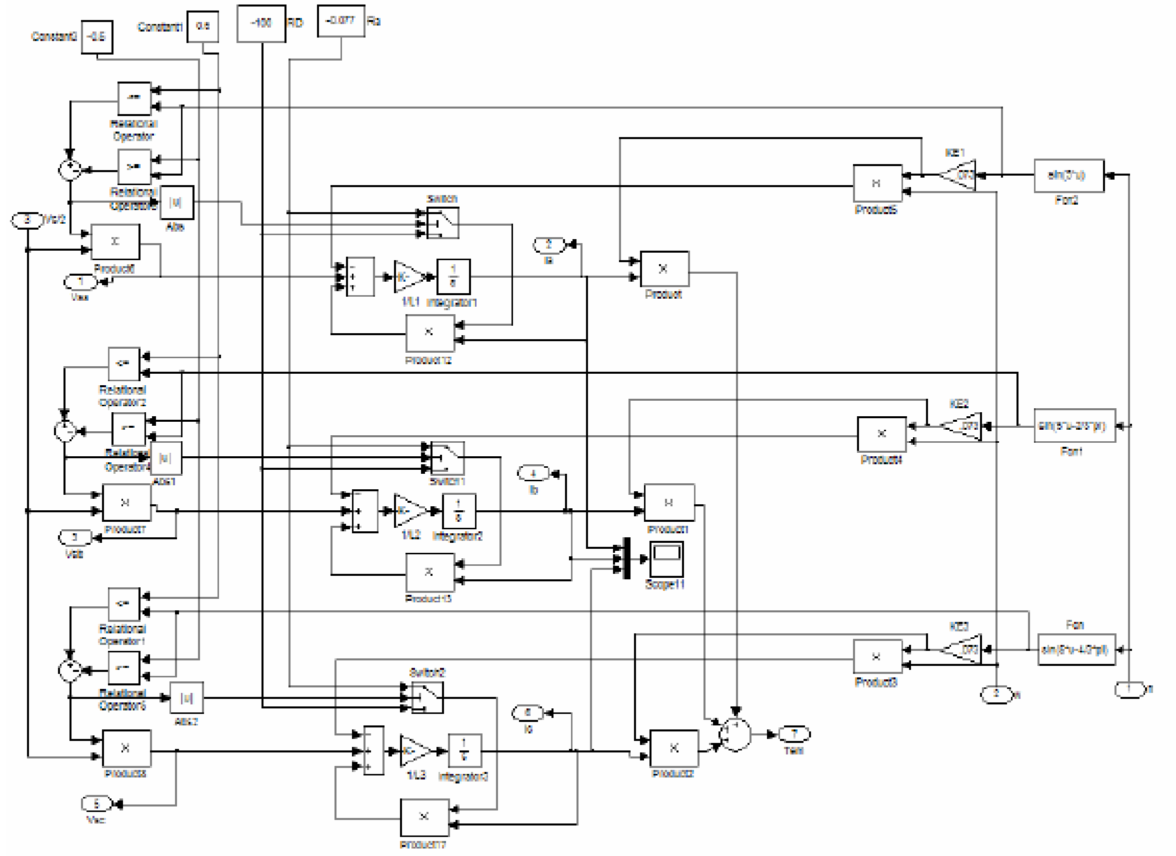
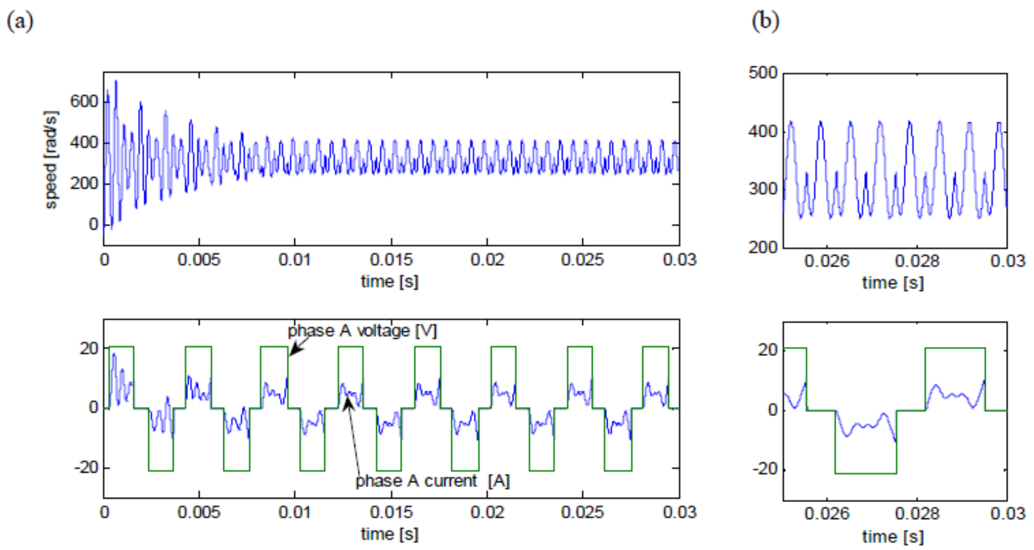


Fig: 4.2.Block Diagram of Behind Sub System shown in Fig.4.1.

V. RESULTS & DISCUSSION



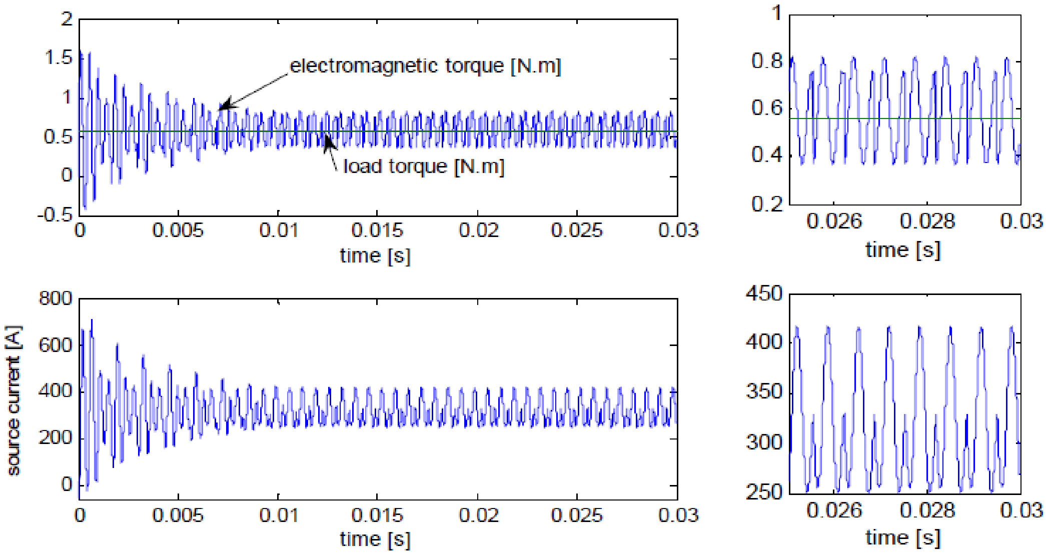


Fig. 5.1 Waveforms of electromechanical quantities obtained from: (a) the start-up Process of the BLDC motor, (b) steady-state.

$$Eff(\%) = \frac{P_L}{P_{in}}.100$$

Where the load power on the motor shaft,

$$P_L = T_L \omega_m$$

and the input power of the inverter equal to the input power of the motor,

$$P_{in} = V_s I_s$$

The above quantities were calculated as average values while the current as an rms value.

VI. CONCLUSION

The performance of a 3-phase permanent magnet motor operating as a synchronous and BLDC motor was analyzed in this paper. The motor performed quite differently under these two different schemes. To examine these differences, the software package MATLAB/SIMULINK was used to design the block diagrams and run the simulations. Models in both steady-state and dynamic conditions were taken into consideration.

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