CHAPTER 2

STATE SPACE MODEL OF BLDC MOTOR

2.1 INTRODUCTION

Modelling and simulation have been an essential part of control system. The importance of modelling and simulation is increasing with the combination of control approaches. Also, its analysis for BLDCM depends on computer programming and can effectively condense development cycle of position sensorless BLDCM control system. Further, it evaluates rationality of the control algorithm imposed on the system. This provides a good foundation for system model and verify novel control strategy. MATLAB (MATLAB 7.3 2006) is an interactive software system developed by Mathworks company for system simulation. It possess powerful scientific computing and graphics processing function.

In paper (Navidi et al 2009), BLDC motor has been modeled based on transfer function description. Though the transfer function model provides us with simple, powerful analysis and design techniques, it suffers from certain drawbacks. They are, i) transfer function is only defined under zero initial conditions; ii) it is applicable to linear time-invariant systems; and iii) it is generally restricted to single input single output systems. Another limitation of the transfer function technique is that, it reveals only the system output for a given input and provides no information regarding the intermediate variables of the system.
In this chapter, the motor is modeled based on state space description to get information about the state of the system variables at some predetermined points along the flow of signals. By adopting this model, powerful processor requirement, large random access memory can be avoided with more design flexibility and faster results can be obtained. To control the speed of the state space modeled BLDC motor, PI controller is used and its simulation performance is tested to verify the theoretical analysis. This study is useful for the comparison purpose when intelligent controllers with a new proposed soft-switching inverter are used.

### 2.2 CONSTRUCTION OF BRUSHLESS DC MOTOR

BLDC motor is a kind of Permanent Magnet Synchronous Motor (PMSM), which has permanent magnets on the rotor and it has trapezoidal back EMF (Duane 1994). The BLDC motor utilizes a dc power supply switched to the stator phase windings of the motor by power electronic switching devices, the switching sequence being determined from the rotor position. To produce constant torque at a constant speed, the phase current of BLDC motor is typically rectangular in shape, and is synchronized with the back EMF. The mechanical commutator of the dc motor is replaced by electronic switches, which supply current to the stator windings, where the current switching is a function of the rotor position. This type of AC motor is called BLDC motor, since its performance is similar to the conventional dc motor with commutators. The BLDC motor is also called as electronically commutated motor (Duane 1994) because there are no brushes on the rotor and commutation is performed electronically at certain rotor positions. The stator magnetic circuit is usually made from magnetic steel sheets. Stator phase has distributed windings which are inserted in the slots as shown in Figure 2.1, or it can be wound as one coil on the magnetic pole.
Magnetization of the permanent magnets and their displacement on the rotor are chosen in such a way that the back EMF shape is trapezoidal. This allows a rectangular shaped three phase voltage system as shown in Figure 2.2 to be used to create a rotational field with low torque ripples (Jacek & Mitchell 2002).

Figure 2.1 Cross Sectional View of BLDC motor
The motor can have more than one pole pair per phase. This defines the ratio between the electrical revolution and the mechanical revolution. The BLDC motor shown has three pole pairs per phase, which represents three electrical revolution per one mechanical revolution (Miller 1989). It is easy to create rectangular shape of applied voltage that ensures the simplicity of drives control. But, the rotor position must be known at certain angles in order to align the applied voltage with the back EMF. The alignment between back EMF and commutation events is very important. Under this condition, the motor behaves as a dc motor and runs at the best working point. Hence, simplicity of control and good performance make this motor suitable for low cost and high efficiency applications.

BLDC motors are a type of synchronous motor (Duane 1994; Jacek & Mitchell 2002), in which the magnetic field generated by the stator and by the rotor rotate at the same frequency. As induction motor, BLDC motor does not experience the slip. Generally BLDC motor comes with single phase, 2-phase and 3-phase configurations. Corresponding to its type, the stator has same number of windings as that of rotor. In general out of these, 3-phase motors are more popular and widely used. All BLDC motors are equipped with Hall sensors instead of brushes and commutator.

2.2.1 Stator

The stator of a BLDC motor is made of stacked steel laminations (Duane 1994; Jacek & Mitchell 2002) with windings placed in the inner periphery of the slots as shown in Figure 2.3. Usually, the stator resembles that of an induction motor. However, the windings are distributed in a different manner. Most of the BLDC motors have three stator windings connected in star fashion. Each of these windings is constructed with numerous coils interconnected to form a winding. One or more coils are
placed in the slots and they are interconnected to make a distributed winding over the stator periphery to form an even number of poles. Depending upon the type of connections, the BLDC motors are identified as trapezoidal back EMF or sinusoidal back EMF motors. If the interconnections of coils in the stator windings produce back EMF in trapezoidal fashion it is called trapezoidal back EMF BLDC motor. On the other hand, if the back EMF produced is sinusoidal, it is called sinusoidal back EMF BLDC motor.

![Stator of a BLDC Motor](image)

**Figure 2.3 Stator of a BLDC Motor**

As their names indicate, the trapezoidal motor gives a back EMF in trapezoidal fashion and the sinusoidal motor’s back EMF is sinusoidal as shown in Figure 2.4 and 2.5. Besides to the back EMF, the phase current also has trapezoidal and sinusoidal variations in the respective types of motor. Hence sinusoidal motor produce smooth output torque than that of a trapezoidal motor.
However, this comes with an extra cost, as the sinusoidal motors need extra interconnection windings because of the coils distribution on the stator periphery. Hence it consumes more copper wires in the stator windings. Depending upon the control power supply capability, the motor with the correct voltage rating of the stator can be chosen. Forty eight volts or less rated motors are used in automotive, robotics, small arm movements and so on. Motors with 100 volts or higher ratings are used in automation and industrial applications.

Figure 2.4 Trapezoidal Back EMF
The rotor is made up of permanent magnet. Based on the required magnetic field density in the rotor, the proper magnetic material is chosen for the rotor (Kenjo & Nagamori 1985). Ferrite magnets are usually used to make permanent magnets. As the technology advances, rare earth alloy magnets are gaining popularity. Generally surface mounted rotor topology is adopted for PMBLDC motors as shown in Figure 2.6.
2.2.3 Hall Sensors

The commutation of a BLDC motor is controlled electronically unlike a brushed DC motor. To rotate the BLDC motor, the stator windings should be energized in a proper sequence with the help of rotor position signals (Kenjo 1985). Rotor position is sensed using Hall effect sensors embedded into the stator. Most of the 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 is determined.
Figure 2.7 BLDC Motor Transverse Section

Figure 2.7 shows a transverse section of a BLDC motor with a rotor that has alternate N and S permanent magnets. Hall sensors are embedded into the stationary part of the motor. Embedding the Hall sensors into the stator is a complex process because any misalignment in these Hall sensors, with respect to the rotor magnets, will generate an error in determination of the rotor position. The Hall sensors may be placed with 60° or 120° phase shift to each other. Based on this, the motor manufacturer defines the commutation sequence, which should be followed when controlling the motor performance.

BLDC motors have many advantages while compared with induction motor as well as conventional dc motor. They have high reliability, large output torque, high power density, high efficiency, low inertia, fast response, maintenance-free reputation, better torque/speed characteristics. BLDC motors have few disadvantages too. The motor field cannot be easily controlled, power rating is restricted because of the maximum available size of permanent magnets, requires a rotor position sensor and it also requires a power semiconductor switching circuits.

2.3 PARAMETERS OF THE BLDC MOTOR UNDER TEST

The Parameters of the machine under test as given by the manufacturers is shown in Table 2.1.
### Table 2.1 BLDC Motor Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Input Voltage</td>
<td>$V_{in}$</td>
<td>24 V</td>
</tr>
<tr>
<td>Rated Armature Current</td>
<td>$I_a$</td>
<td>10.4 A</td>
</tr>
<tr>
<td>Rated Speed</td>
<td>$N$</td>
<td>1500 rpm</td>
</tr>
<tr>
<td>Armature Resistance</td>
<td>$R_a$</td>
<td>0.3 Ω</td>
</tr>
<tr>
<td>Armature Inductance</td>
<td>$L_a$</td>
<td>1.15 mH</td>
</tr>
<tr>
<td>Magnetic Flux Linkage</td>
<td>$\Phi$</td>
<td>0.20wb</td>
</tr>
<tr>
<td>No. of Poles</td>
<td>$P$</td>
<td>4</td>
</tr>
<tr>
<td>Moment of Inertia</td>
<td>$J$</td>
<td>0.002 kg.m$^2$</td>
</tr>
<tr>
<td>Friction Factor</td>
<td>$B$ (or) $F$</td>
<td>0.0001 Nm.s/rad</td>
</tr>
<tr>
<td>Induced EMF Constant</td>
<td>$K_e$</td>
<td>0.1959 V/(rad/s)</td>
</tr>
</tbody>
</table>

### 2.4 STATE SPACE MODEL OF THE BLDC MOTOR

Before modeling the BLDC motor using state space analysis, the following assumptions are made:

1) The motor’s stator is a star wound type,

2) The motor’s three phase are symmetric, including their resistance, inductance and mutual inductance (Figueroa et al 2003),

3) There is no change in rotor reluctance with angle due to non-salient rotor,

4) There is no misalignment between each magnet and the corresponding stator winding,

5) The motor is not saturated,
6) All three phases have an identical back-EMF shape,

7) Power semiconductor devices in the inverter are ideal,

8) Iron losses are negligible,

9) Eddy current and hysteresis effects are neglected.

The coupled circuit equation (Duane 1994) of the stator winding in terms of motor electrical constants are

\[
\begin{bmatrix}
V_{\text{as}}-V_n \\
V_{\text{bs}}-V_n \\
V_{\text{cs}}-V_n
\end{bmatrix} =
\begin{bmatrix}
R_s & 0 & 0 \\
0 & R_s & 0 \\
0 & 0 & R_s
\end{bmatrix}
\begin{bmatrix}
I_a \\
I_b \\
I_c
\end{bmatrix} +
P \begin{bmatrix}
L_{aa} & L_{ab} & L_{ac} \\
L_{ba} & L_{bb} & L_{bc} \\
L_{ca} & L_{cb} & L_{cc}
\end{bmatrix}
\begin{bmatrix}
I_a \\
I_b \\
I_c
\end{bmatrix} +
\begin{bmatrix}
E_a \\
E_b \\
E_c
\end{bmatrix}
\]

(2.1)

where \( R_s \) is the stator resistance per phase, \( I_a, I_b, I_c \) are the stator phase currents, \( p \) is the time derivative operator, \( E_a, E_b, E_c \) are the back emfs in the respective phases in (2.1) and \( V_n \) is the neutral point node voltage which is given by

\[
V_n = \frac{1}{3} \left[ V_{\text{as}} + V_{\text{bs}} + V_{\text{cs}} \right] - \sum \text{BEMFs}
\]

(2.2)

where \( \sum \text{BEMFs} \) means summing up the individual phase emfs on an instant to instant basis.

Based on Equation (2.1), the equivalent circuit of motors can be obtained as shown in Figure 2.8.
The induced emfs are all assumed to be trapezoidal, whose peak value is given by

\[ E_p = (BLv)N = N(Blr\omega) = N\Phi(\omega) = \lambda(\omega) \quad (2.3) \]

where \( B \) is the flux density of the field in webers, \( L \) is the rotor length, \( N \) is the number of turns per phase, \( \omega \) is the electrical angular speed in rad/sec, \( \Phi \) represents flux linkage = \( BLr \) and \( \lambda \) represents the total flux linkage which is given as the product of number of conductors and flux linkage/conductor.

Assuming that the three phases are symmetric, with same self and mutual inductances and the change in rotor reluctance is negligible with the change in rotor position (Krishnan 2007), equation (2.1) is written as

\[
\begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix} = R_s \begin{bmatrix}
1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
I_a \\
I_b \\
I_c
\end{bmatrix} + P \begin{bmatrix}
L & M & M \\
M & L & M \\
M & M & L
\end{bmatrix} \begin{bmatrix}
I_a \\
I_b \\
I_c
\end{bmatrix} + \begin{bmatrix}
E_a \\
E_b \\
E_c
\end{bmatrix} 
\]  

(2.4)

Simplifying (2.4) we get the following equation
\[
\begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix} = R_s^* \begin{bmatrix}
1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
I_a \\
I_b \\
I_c
\end{bmatrix} + P \begin{bmatrix}
L-M & 0 & 0 \\
0 & L-M & 0 \\
0 & 0 & L-M
\end{bmatrix} \begin{bmatrix}
I_a \\
I_b \\
I_c
\end{bmatrix} + \begin{bmatrix}
E_a \\
E_b \\
E_c
\end{bmatrix}
\] (2.5)

The generated electromagnetic torque is given by

\[
T_e = \frac{\left[E_a I_a + E_b I_b + E_c I_c\right]}{\omega} \text{ (in Nm)}
\] (2.6)

The induced emfs is written as

\[
\begin{align*}
E_a &= f_a(\theta) \lambda \omega \\
E_b &= f_b(\theta) \lambda \omega \\
E_c &= f_c(\theta) \lambda \omega
\end{align*}
\] (2.7)

where \(f_a(\theta), f_b(\theta), f_c(\theta)\) are functions having same shapes as back emfs and are given below.

\[
f_a(\theta) = \begin{bmatrix}
E & (0 < \theta < \pi/6) \\
-(6E/\pi)\theta + 2E & (\pi/6 < \theta < \pi/2) \\
-E & (\pi/2 < \theta < 7\pi/6) \\
(6E/\pi)\theta - 8E & (7\pi/6 < \theta < 9\pi/6) \\
E & (9\pi/6 < \theta < 2\pi)
\end{bmatrix}
\] (2.8)

\[
f_b(\theta) = \begin{bmatrix}
-E & (0 < \theta < \pi/2) \\
(6E/\pi)\theta - 4E & (\pi/2 < \theta < 5\pi/6) \\
E & (5\pi/6 < \theta < 9\pi/6) \\
-(6E/\pi)\theta + 10E & (9\pi/6 < \theta < 11\pi/6) \\
E & (11\pi/6 < \theta < 2\pi)
\end{bmatrix}
\] (2.9)
Substituting $E_a$, $E_b$ and $E_c$ from (2.5) in (2.6) the torque equation is obtained. The electro-mechanical torque equation for the motor is written as

$$J \frac{d\theta}{dt} + B\omega = T_e - T_l$$  \hspace{1cm} (2.11)$$

where $T_l$ is the load torque, $J$ is the moment of inertia in kgm$^2$, $B$ is the friction coefficient in Nm/rad/sec. Electrical rotor speed and position are related by

$$\frac{d\theta}{dt} = \left(\frac{P}{2}\right)\omega$$  \hspace{1cm} (2.12)$$

where $P$ is the number of poles in the motor. From the above equations, the system state equations are written in the following form

$$\dot{x}(t) = Ax(t) + Bu(t)$$  \hspace{1cm} (2.13)$$

where the states are chosen as $x(t) = [I_a \ I_b \ I_c \ \omega \ \theta]^T$  \hspace{1cm} (2.14)$$

Thus the system matrices are given below,

$$A = \begin{bmatrix}
-R_s/L_i & 0 & 0 & (\lambda_p \ast f_a(\theta)) / J & 0 \\
0 & -R_s/L_i & 0 & (\lambda_p \ast f_b(\theta)) / J & 0 \\
0 & 0 & -R_s/L_i & (\lambda_p \ast f_c(\theta)) / J & 0 \\
(\lambda_p \ast f_a(\theta)) / J & (\lambda_p \ast f_b(\theta)) / J & (\lambda_p \ast f_c(\theta)) / J & -B/J & 0 \\
0 & 0 & 0 & P/2 & 0
\end{bmatrix}$$  \hspace{1cm} (2.15)$$
\[ B = \begin{bmatrix} 1/L_1 & 0 & 0 & 0 \\ 0 & 1/L_1 & 0 & 0 \\ 0 & 0 & 1/L_1 & 0 \\ 0 & 0 & 0 & -1/J \end{bmatrix} \]

(2.16)

The input vector is defined as
\[ u(t) = [V_a \ V_b \ V_c \ T_1]^T \]  

(2.17)

where \( L_1 = L - M \), \( L \) is the self inductance of the winding per phase, \( M \) is the mutual inductance per phase and \( V_a, V_b, V_c \) are the per phase impressed voltage on the motor windings. All the equations form the entire state space model for the BLDC motor.

2.5 BLDC MOTOR PRINCIPLE OF OPERATION

The three phase BLDC motor is operated efficiently with the help of rotor position signals. At any time interval, two phases that produce highest torque are energized while the third phase is in off condition. The position sensors (H1, H2, H3) signal produces a three digit number that changes every 60° electrical degrees as shown in Figure 2.9. Moreover, the Figure 2.9 also shows ideal current and back EMF waveforms.

Figure 2.10 shows a cross sectional view of an three phase star connected BLDC Motor along with its phase energizing sequence. Each interval starts with the rotor and stator field lines 120° apart and ends when they are 60° apart. When the field lines are perpendicular, the torque reaches its maximum. Current commutation is done by a six-step inverter as shown in Figure 2.11. In Figure 2.11, the switches are shown as bipolar junction transistors but MOSFET switches are used widely. The switching sequence, position sensor signals and the current direction are shown in Table 2.2.
Figure 2.9  Position Sensor Signals, Ideal back EMF’s and Phase Currents

Figure 2.10 Cross Section of BLDC Motor and Phase Energizing Sequence
Figure 2.11 Simplified BLDC Drive Scheme

Table 2.2 Switching Sequence

<table>
<thead>
<tr>
<th>Switching Interval</th>
<th>Seq. No.</th>
<th>Position Sensors</th>
<th>Switch Closed</th>
<th>Phase Current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>H1</td>
<td>H2</td>
<td>H3</td>
</tr>
<tr>
<td>0º - 60º</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>60º - 120º</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>120º - 180º</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>180º - 240º</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>240º - 300º</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>300º - 360º</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

2.6 TORQUE SPEED CHARACTERISTICS

The dc terminal voltage is written as Equation (2.18), when the commutation is perfect and the current waveforms are exactly matched with ideal BLDC motor and if the converter is supplied from an ideal direct voltage source \( V \).

\[
V = E + RI \tag{2.18}
\]

where,
\[ R \rightarrow \text{sum of two phase resistance in series} \]

\[ E \rightarrow \text{sum of two phase EMF's in series} \]

This equation is exactly same as that of commutator motor. The voltage drops across two converter switches in series are omitted, but they correspond exactly to the two brush voltage drops in series in the commutator motor. The torque/speed characteristic can be derived using the above equation together with EMF and torque equations as

\[
\omega = \omega_0 \left[1 - \frac{T}{T_0}\right] \tag{2.19}
\]

where the no-load speed is

\[
\omega_0 = \frac{V}{k\Phi} \text{ rad/sec} \tag{2.20}
\]

and the stall torque is given by

\[ T_0 = k\Phi I_0 \tag{2.21} \]

Stall torque is the torque of the motor at zero speed. The stall current is given by

\[ I_0 = \frac{V}{R} \tag{2.22} \]

This characteristic is plotted in Figure 2.12. In an efficient design, if the phase resistance is small, then the characteristic is similar to that of a dc shunt motor. The speed is effectively controlled by varying the supply voltage \(V\). The motor then takes sufficient current to drive the torque at this speed. As the load torque is increased, the speed drops and it is directly proportional to the phase resistance and torque. The voltage is usually controlled by chopping or PWM. This gives rise to a family of torque/speed characteristics as shown in Figure 2.12.
2.7 SIMULATION OF THE BLDC MOTOR MODEL

The simulation model has five main blocks. They are BLDC motor, controller block, inverter block, estimate block and changer block as shown in Figure 2.13. Each main block has several sub-blocks. Some blocks are logical and some are made using S-Function. The BLDC motor block contains state space sub-block where matrices A, B, C, D are located with the provision that the initial condition can be varied. In the S-Function, coding file is linked and is shown in Figure 2.14.

The sequence of operation of the above blocks are described by the flowchart shown in Figure 2.15. The simulation starts with a starter block (No. 1 in chart) that generates 3Φ input voltage to the system’s core block (No.2 in chart) for one cycle. A changer block is used to close the control loop after the random ramping of the motor. Once the loop is closed, the starter block will be disconnected from the system and the motor will start receiving the phase voltages from the connected controller through inverter.
Figure 2.13  Simulink Model of BLDC Motor
The PID controller is tuned by Ziegler Nichols method. By this method, the values of $K_p=3.3$, $K_i=1.30$ and $K_d=0$ are chosen. An S-Function block is connected to the state space block to choose the motor specifications such as, the number of conductor turns per phase, resistance per phase, rotor dimensions etc as defined by the user. The S-Function will read the instantaneous position among twelve position which are separated by 30º. Depending on the position (Dixon et al 2002), the back e.m.f and torque in each phase will be defined. The estimate block contains the PID controller. The block again is an M-file S-Function. This block calculates the reference phase current from the speed and required torque. Required torque is calculated by actual speed and the speed error value. The above value will be read and used in a PID controller (Palani & Anoop 2013). The required torque is calculated as follows,
\[
T_{\text{req}} = \left[ e(t) \times \left( K_p + (K_i \times 0.5 \times t_s) + \frac{K_d}{t_s} \right) \right] + \left[ e_{-1}(t) \times \left( 0.5 \times t_s \times K_i - \frac{K_d}{t_s} \right) \right]
\]

(2.23)

where \( e(t) \) is the angular speed error, \( e_{-1}(t) \) is the previous time step error in angular speed, \( t_s \) is the sampling time, \( K_p, K_i, K_d \) are proportional, integral and derivative constants.

The required current is calculated from the instantaneous required torque. Then it is converted by means of an approximated Park’s Transformation to three phase currents. The approximated park’s transformation gives the corresponding phase current to every stator phase according to the rotor’s position. A hold block (No.3 in chart) is used to hold on both the required and instantaneous current values in the open loop. Once the changer block closes the control loop, the hold block will give an access to the current values to pass to the present controller scheme. In this simulation, hysteresis controller function is chosen. Usually, the controller is used to fire the gates of six step inverter switches, as in (Somanatham et al 2006).

Each firing scheme determines certain voltage in each phase in the stator. According to the change in the firing angle, stator voltage received by the inverter block changes and the motor speed is varied.
Figure 2.15 Detailed Flow Chart for the Whole Control Process
2.8 SIMULATION RESULTS

The BLDC motor specifications used in this simulation are shown in Table 2.1. The simulation was run for 0.5 seconds (simulation time). When the reference speed equals 1500 rpm, the simulation waveforms of 3Φ back EMFs, 3Φ currents and rotor angle are as shown in Figure 2.16, Figure 2.17 and Figure 2.18, respectively. Load torque is applied at 0.4 seconds. The motor speed stabilizes in 0.24 seconds with 0% overshoot as shown in Figure 2.19. The back emf is almost trapezoidal with 120° phase difference and 3Φ currents with 120° phase difference between each phases are shown in Figure 2.16 and Figure 2.17. From Figure 2.18, the rotor angle can be analyzed.

![Figure 2.16 Three Phase Back EMF](image-url)
Figure 2.17 Three Phase Current

Figure 2.18 Rotor Angle

Figure 2.19 Speed
2.9 SUMMARY

Modeling and simulation have been an essential part of control design, when various methodologies have been developed. Predefined adaptation models and mechanisms obtained by pre-tuning with modeling and simulation, facilitate fast operation in changing process conditions. Though the transfer function model provides us with simple and powerful analysis and design techniques, it suffers from certain drawbacks such as transfer function is only defined under zero initial conditions, it is only applicable to linear time-invariant systems and there too it is generally restricted to single input single output systems. Another limitation of the transfer function model is that it reveals only the system output for a given input and provides no information regarding the internal state of the system.

In this chapter, to overcome the drawbacks of transfer function model, BLDC motor is modeled based on state space description. In order to understand the basic concepts of BLDC motor, its construction and principle of operation have been discussed. From the determination of motor equivalent model parameters, the state space model of the BLDC motor has been derived.

The torque-speed characteristics of BLDC motor has been analysed and state space simulation model with conventional PI controller and hard-switching inverter has been developed and the simulation results of three phase back EMFs, three phase currents, rotor angle and rotor speed are presented. The third chapter explains the design and hardware implementation of soft-switching inverter with PI controller.