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14 April 2020

Design of Brushless DC Motor Driver and Controller

GLISTAR Research Laboratory University of Lahore

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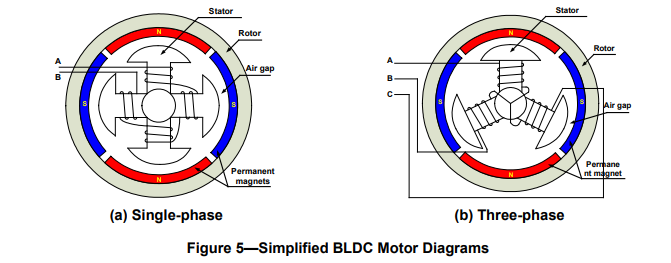
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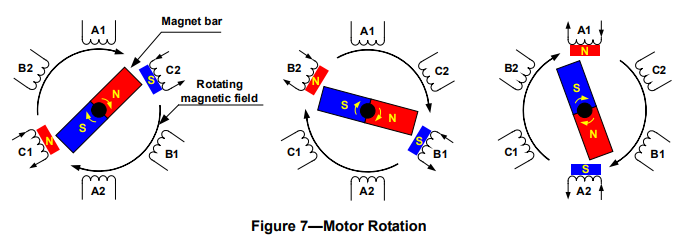
[4.2. Inverter with Optical Isolation 36](#_Toc37710484)

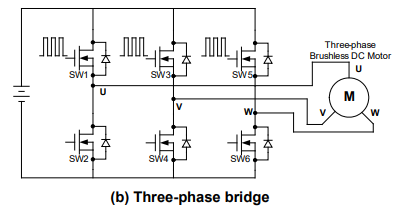
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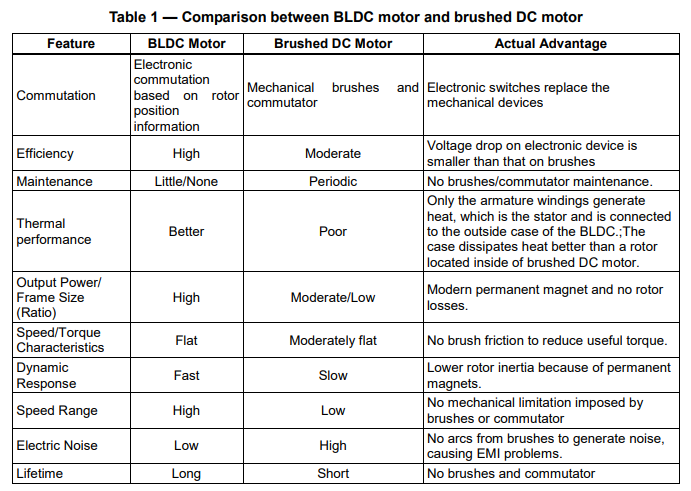
# Working of Brushless DC Motor

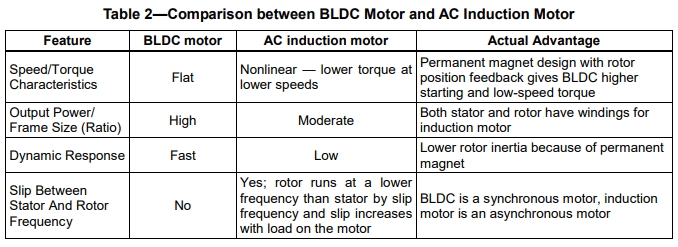
Brushless DC Motor is classified as a synchronous AC Electric Motor.

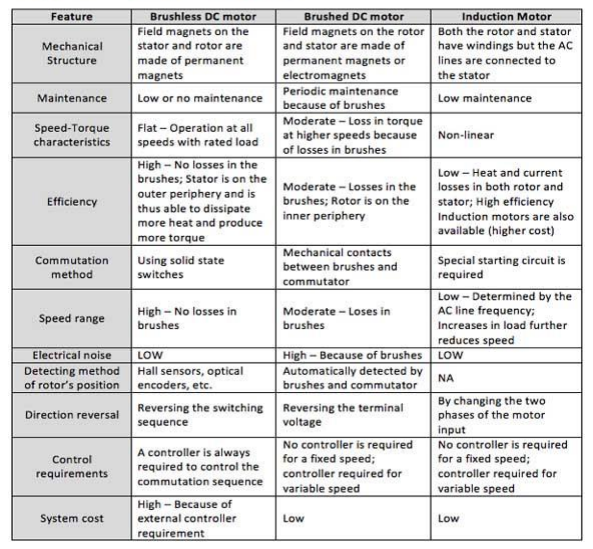


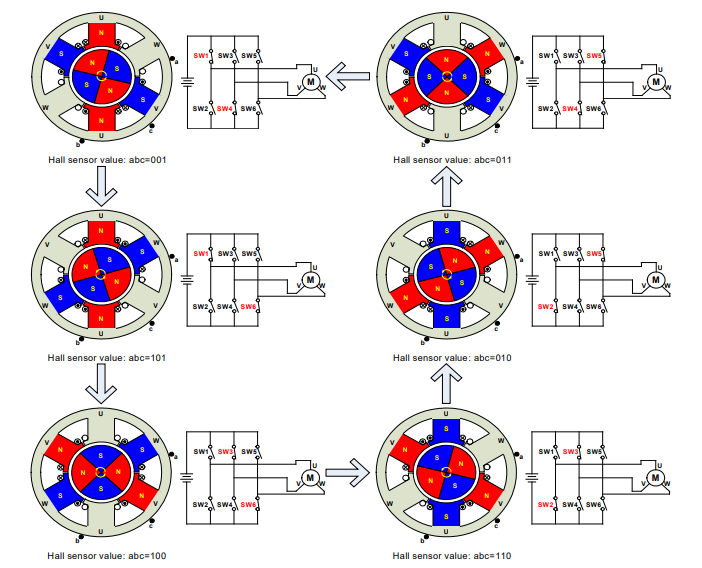


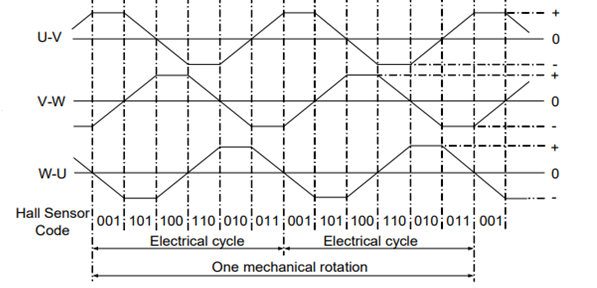
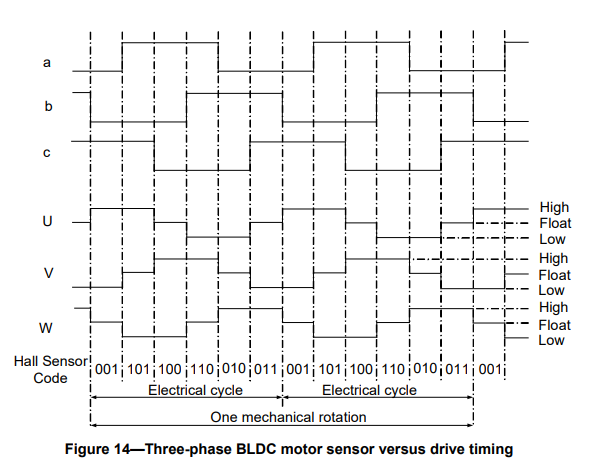


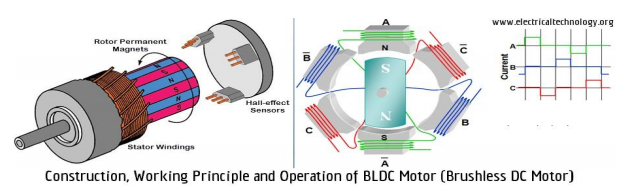


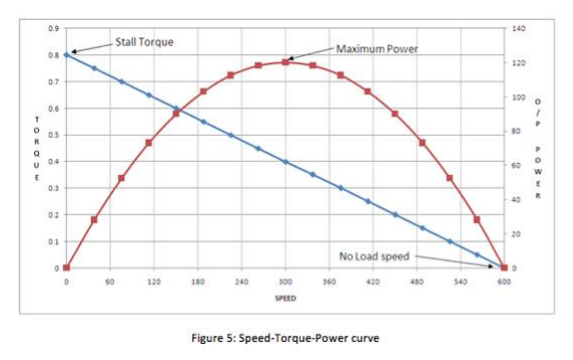


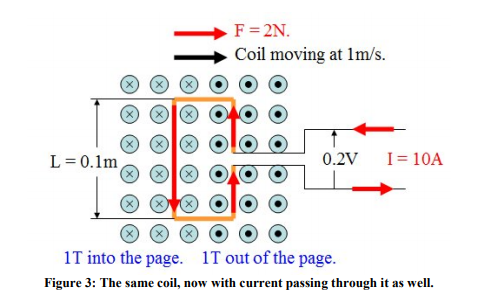






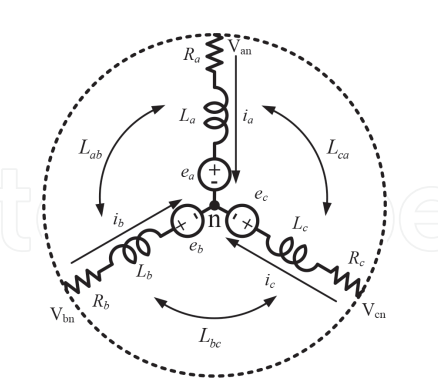




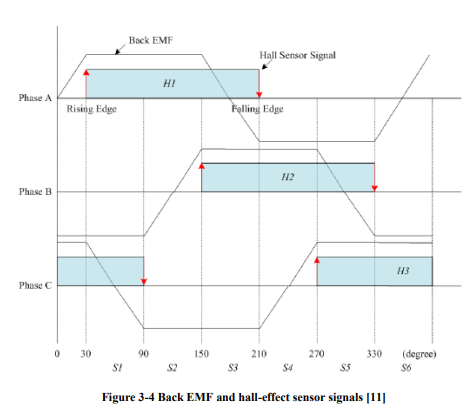


# Modeling of Brushless DC Motor

The equivalent motor electrical circuit is given below.



The motor equations are:



The Hall Signals are represented by

The Mechanical System Equations are,

For a balanced system,

In steady state,

The -axis model of the motor can be obtained by decomposing the voltage, current and flux linkage space-vectors into their corresponding α-axis and β-axis components.

If the α-axis is aligned with the a-axis,

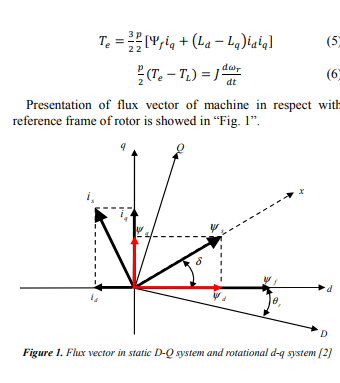
The dq-axis rotating reference frame is derived by substituting θ = :

The -axis model of the motor can be obtained by decomposing the voltage, current and flux linkage space-vectors into their corresponding d-axis and q-axis components.

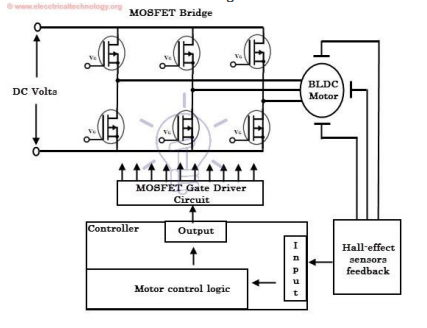
The resulting dq-axis model equations are:

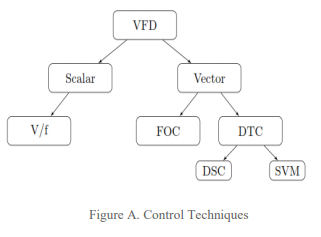
1. Flux Linkage Equations:
2. Voltage Equations
3. Torque Equation

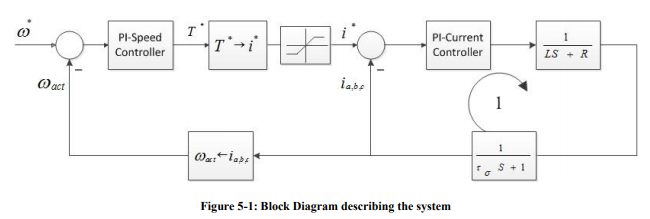
For balanced system,

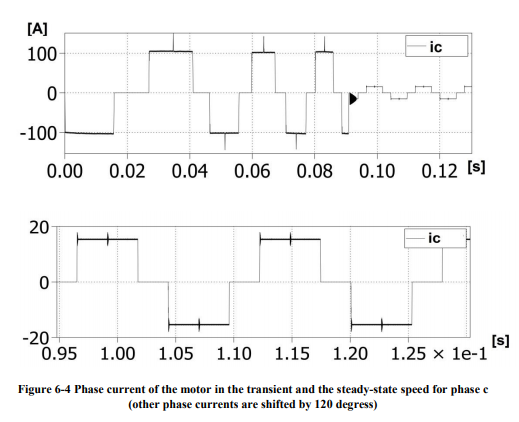


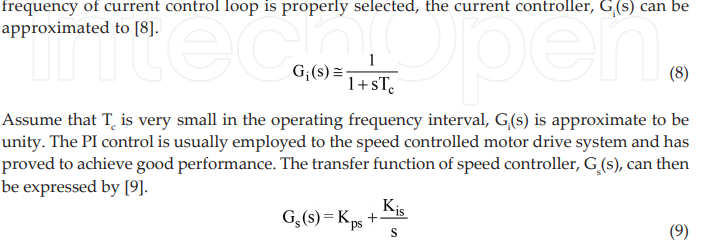
# Design of Brushless DC Motor Controller

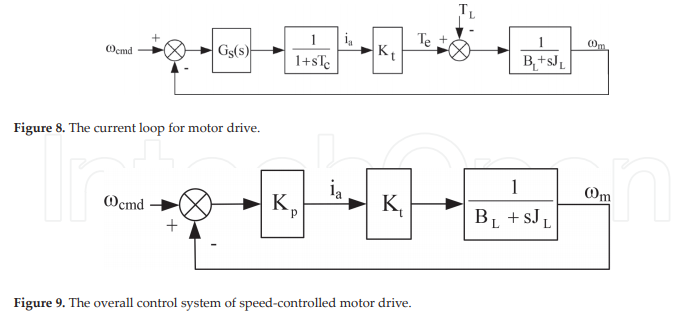


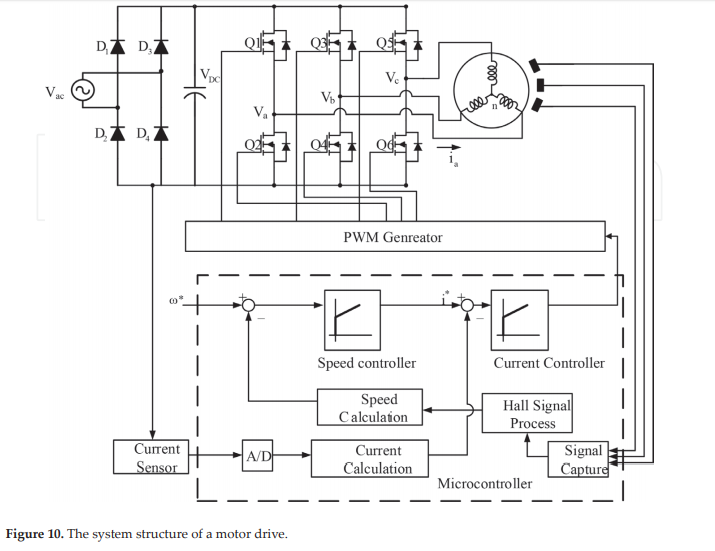




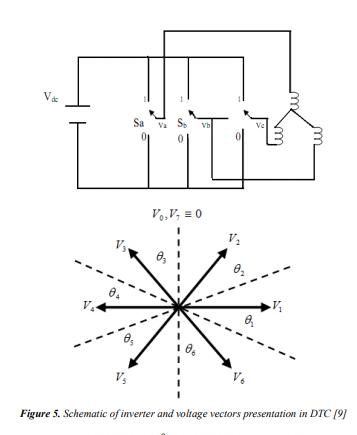


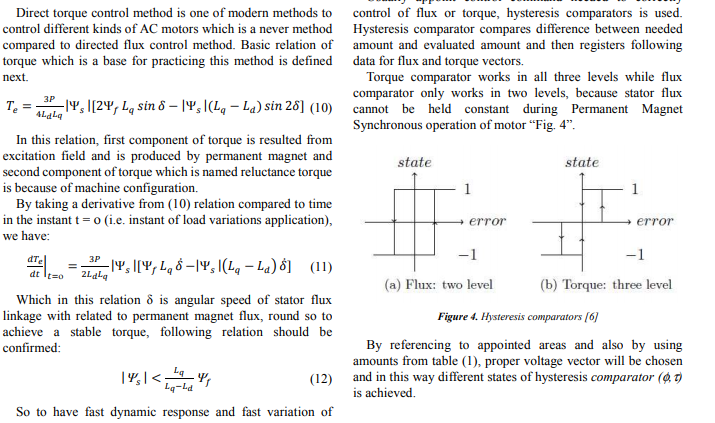


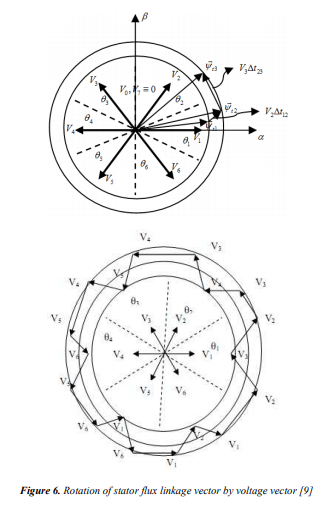


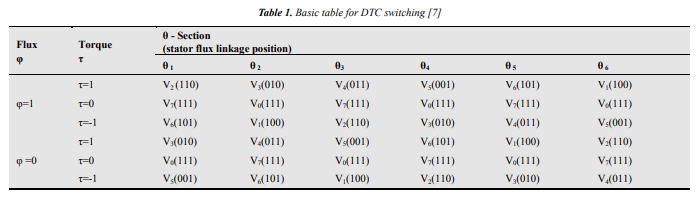


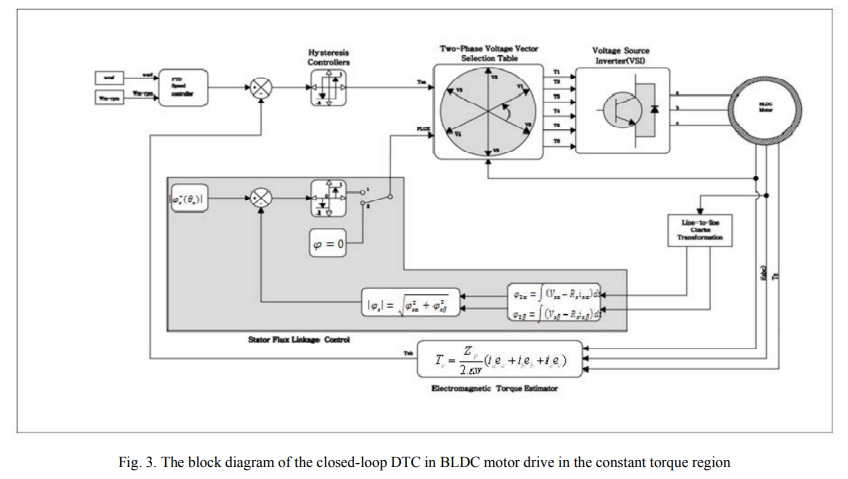
## Direct Torque Control

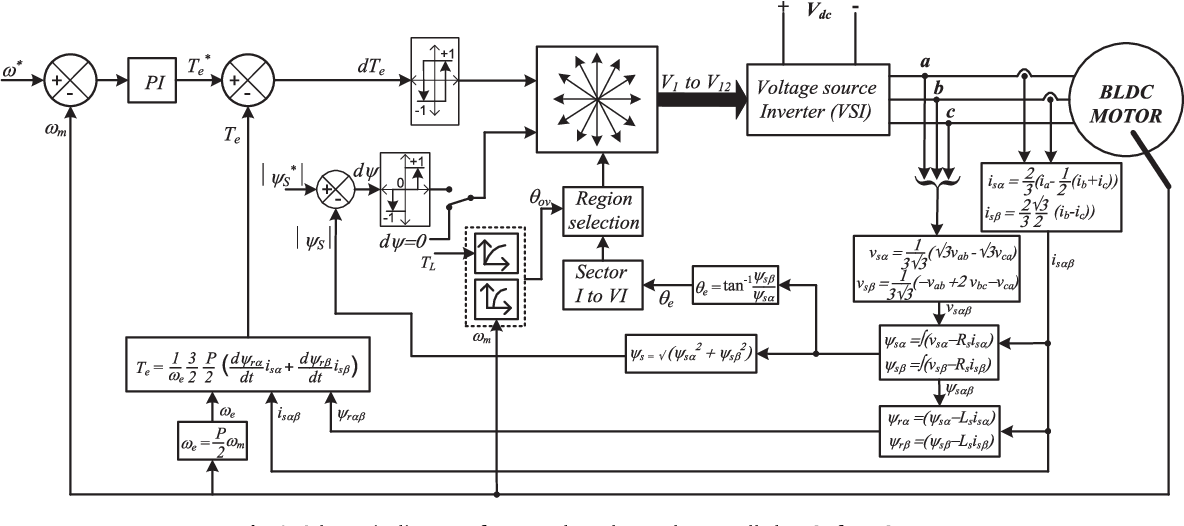




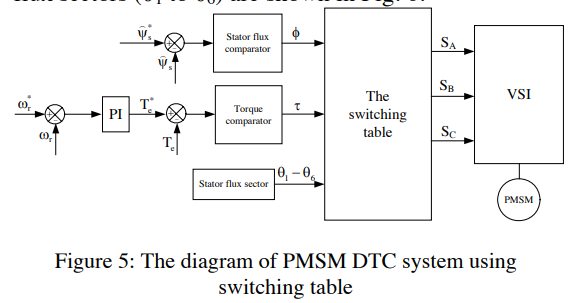


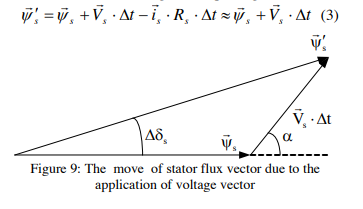


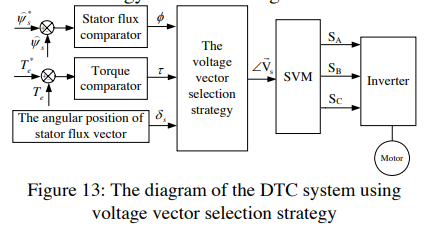




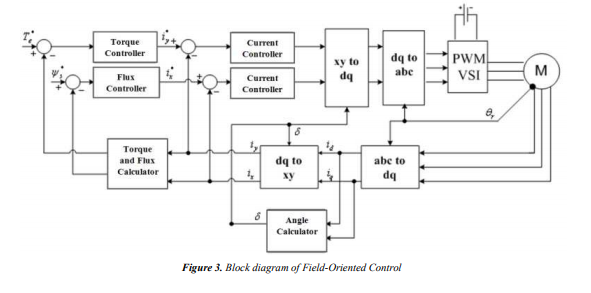


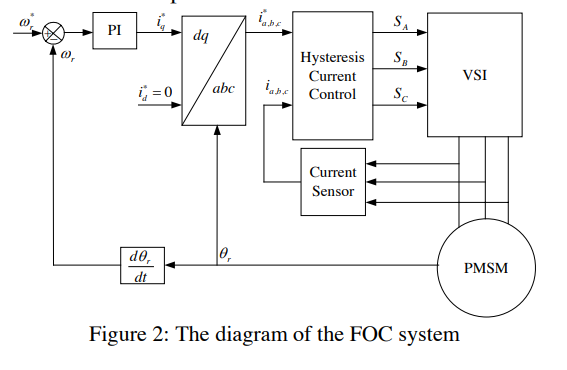




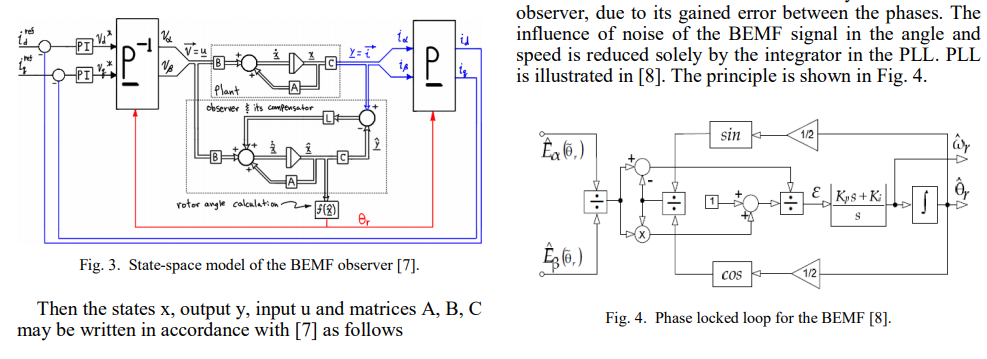


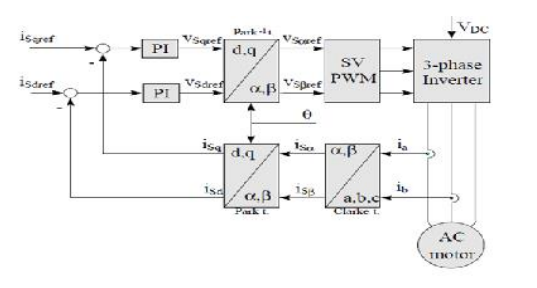
## Field Oriented Control

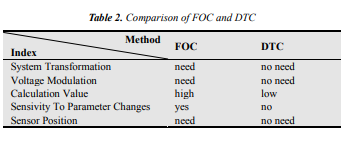








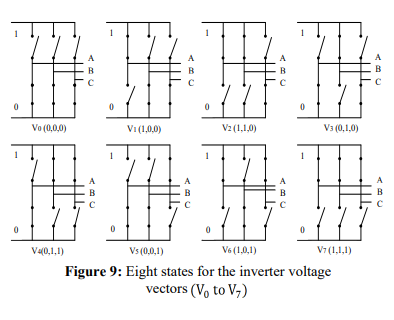




## Space Vector PWM

Space vector modulation (SVM) is a real-time modulation technique widely used for digital control of voltage source inverters. The operating status of the switches in the two-level inverter can be represented by switching states. The switching state ‘P’ denotes that the upper switch in an inverter leg is on and the inverter terminal voltage is positive (+Vdc) while ‘O’ indicates that the inverter terminal voltage is zero due to the conduction of the lower switch. There are eight possible combinations of switching states in the two-level inverter. Among the eight switching states, [PPP] and [OOO] are zero states and the others are active states.





The active and zero switching states can be represented by active and zero space vectors, respectively in the αβ reference frame. The space vector diagram below represents the six active vectors which form a regular hexagon with six equal sectors (I to VI). The zero vector V0 lies on the center of the hexagon.



where k represents the sector.

For a given magnitude and position, can be synthesized by three nearby stationary vectors (OOO, POO and PPO in sector 1), based on which the switching states of the inverter can be selected, and gate signals for the active switches can be generated. When passes through sectors one by one, different sets of switches will be turned on or off. As a result, when rotates one revolution in space, the inverter output voltage varies one cycle over time.

The inverter output frequency corresponds to the rotating speed of while its output voltage can be adjusted by the modulation index:

The dwell time for the stationary vectors represents the duty-cycle time of the chosen switches during a sampling period Ts. The dwell time calculation is based on ‘volt-second balancing’ principle, that is, the product of the reference voltage and sampling period Ts equals the sum of the voltage multiplied by the time interval of chosen space vectors. Assuming that the sampling period Ts is sufficiently small, the reference vector ref v r can be considered constant during Ts. Under this assumption, can be approximated by two adjacent active vectors and one zero vector. Ta , Tb and T0 are the dwell times for the vectors , and , respectively:



When is in other sectors, a multiple of π 3/ is subtracted from the actual angular displacement θ such that the modified angle θ ′ falls into the range between zero and π 3/ for use in the equation, that is,

for 0 ≤ θ′ <

where k = 1, 2, …6 for sectors I, II, …, VI, respectively. For example, when is in sector II, the calculated dwell times Ta, Tb and T0 are for vectors , and respectively.

With the space vectors selected and their dwell times calculated, the next step is to arrange switching sequence. In general, the switching sequence design for a given is not unique, but it should satisfy the following two requirements for the minimization of the device switching frequency:

a) The transition from one switching state to the next involves only two switches in the same inverter leg, one being switched on and the other switched off;

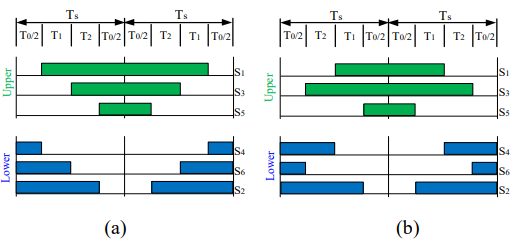
b) The transition for ref v r moving from one sector in the space vector diagram to the next requires no or minimum number of switching.

The optimized seven segment switching sequence is given in the table below.

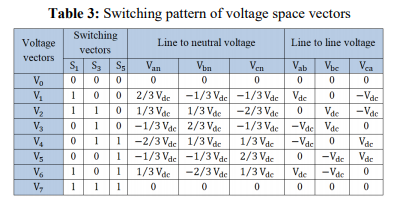


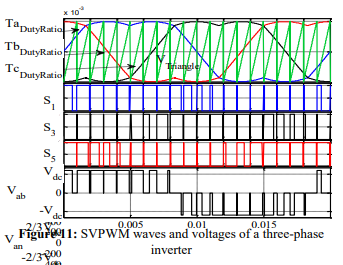
The overall Space Vector Modulation block diagram is given below.



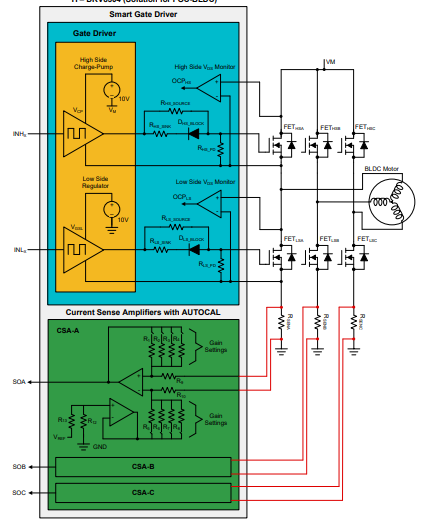




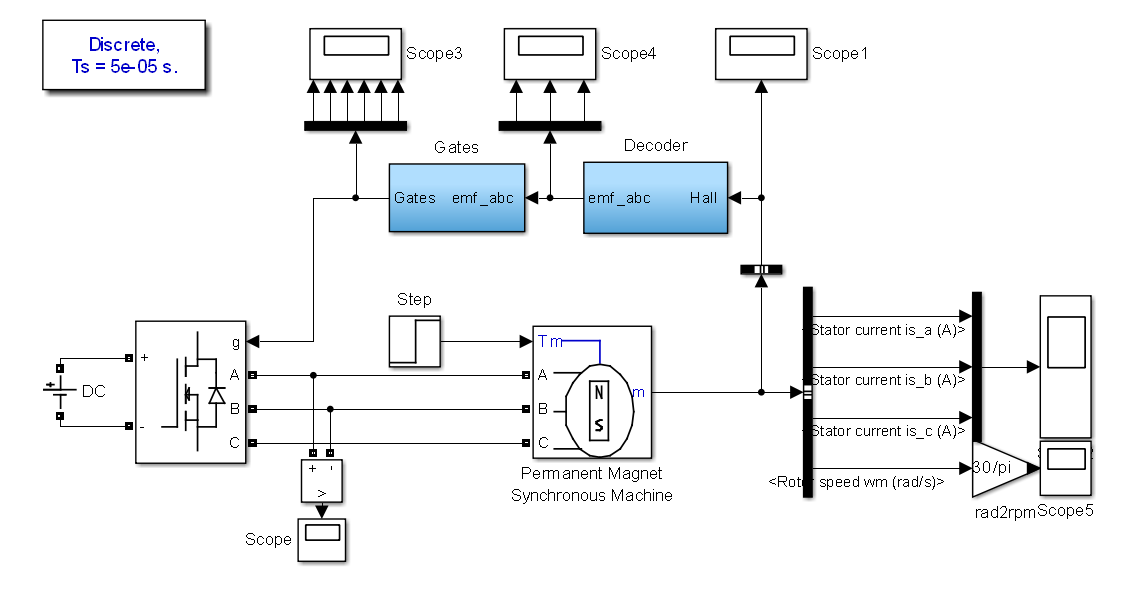


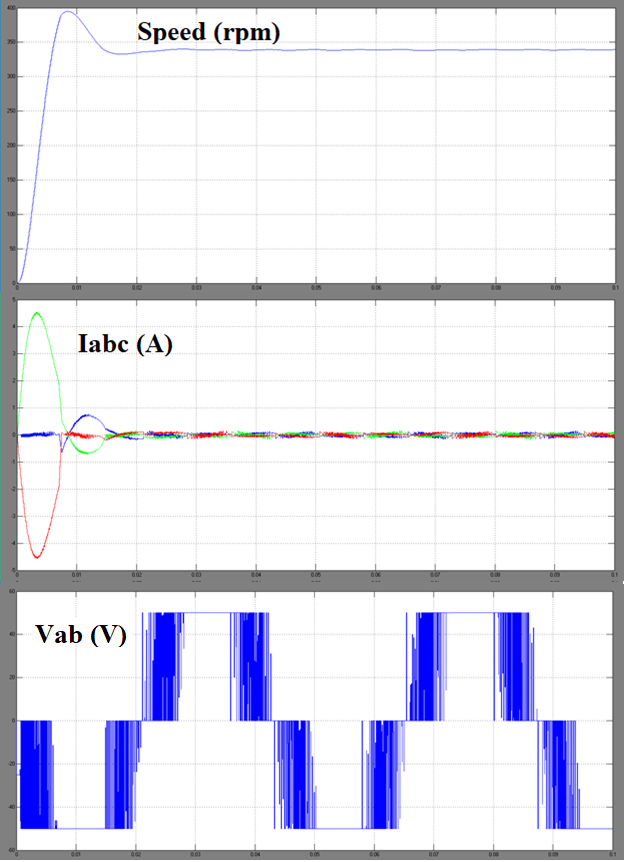


## Safety and Protection of Devices

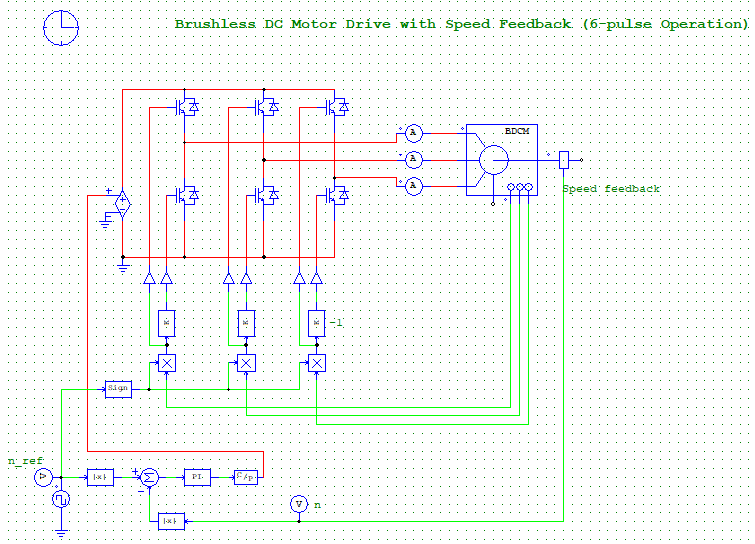


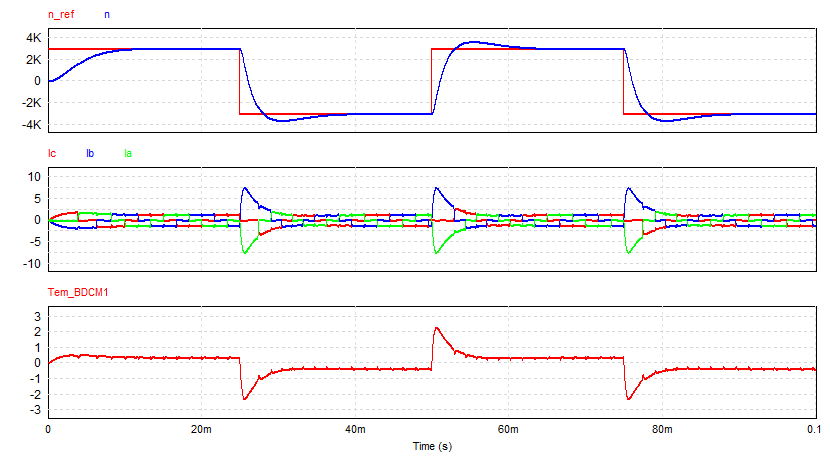
## Open Loop Control



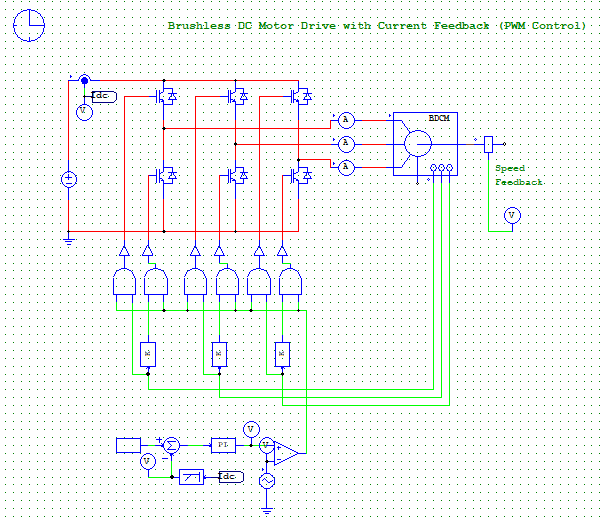


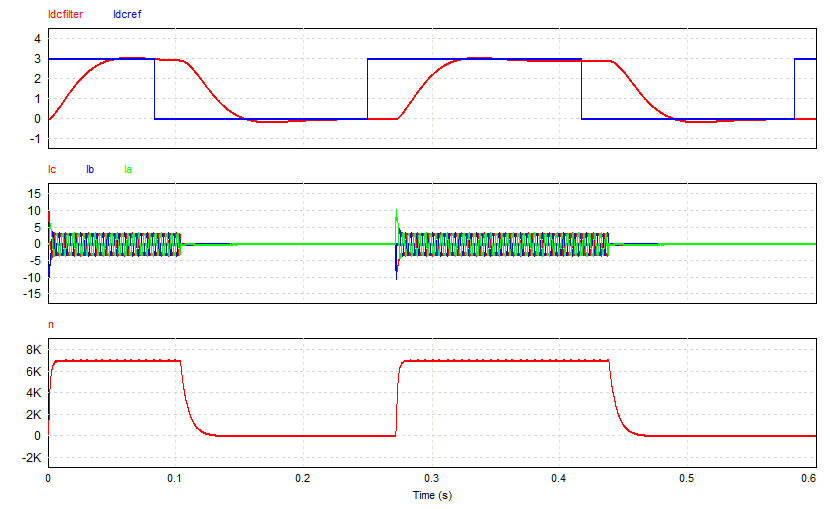
## Speed Control





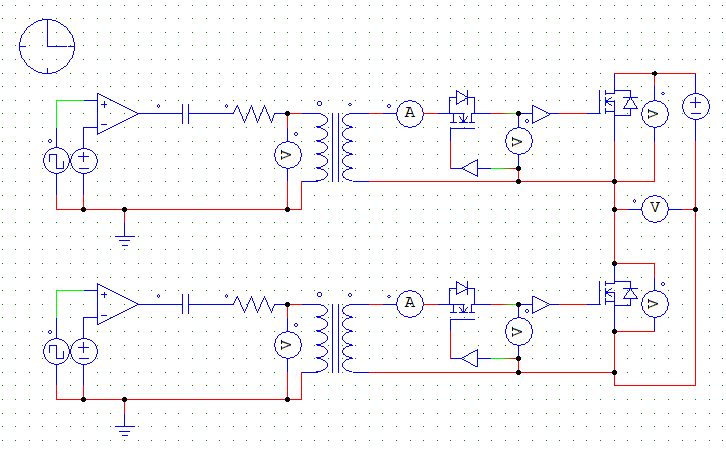
## Current Control

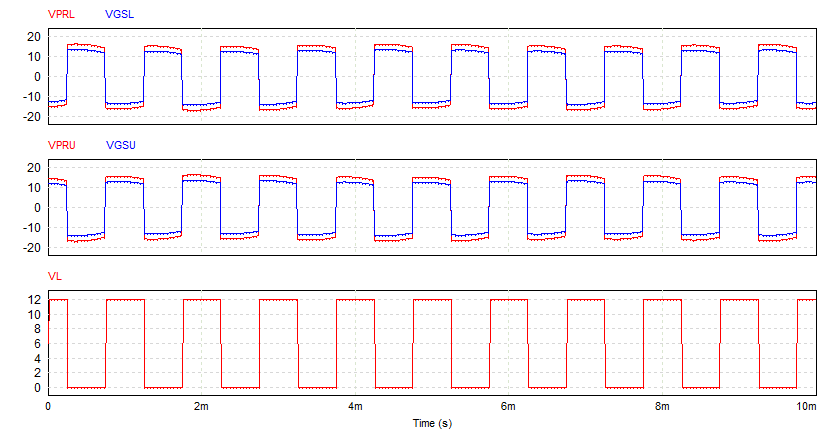




# Progress

## Inverter with Transformer Isolation





**Arduino Code for Inverter**

double frequency = 2500.0; //Set frequency in Hertz

double delayTime = (1000000.0 / (frequency \* 2.0));//Half Period in microseconds

void setup()

{

pinMode(2, OUTPUT);

pinMode(3, OUTPUT);

pinMode(4, OUTPUT);

pinMode(5, OUTPUT);

pinMode(6, OUTPUT);

pinMode(7, OUTPUT);

pinMode(8, OUTPUT);

pinMode(9, OUTPUT);

pinMode(10, OUTPUT);

pinMode(11, OUTPUT);

pinMode(12, OUTPUT);

pinMode(13, OUTPUT);

digitalWrite(2, HIGH);

digitalWrite(3, HIGH);

digitalWrite(4, HIGH);

digitalWrite(5, HIGH);

digitalWrite(6, HIGH);

digitalWrite(7, HIGH);

}

void loop()

{

digitalWrite(8, LOW);

digitalWrite(9, HIGH);

delayMicroseconds(delayTime/3);

digitalWrite(12, HIGH);

digitalWrite(13, LOW);

delayMicroseconds(delayTime/3);

digitalWrite(10, LOW);

digitalWrite(11, HIGH);

delayMicroseconds(delayTime/3);

digitalWrite(8, HIGH);

digitalWrite(9, LOW);

delayMicroseconds(delayTime/3);

digitalWrite(12, LOW);

digitalWrite(13, HIGH);

delayMicroseconds(delayTime/3);

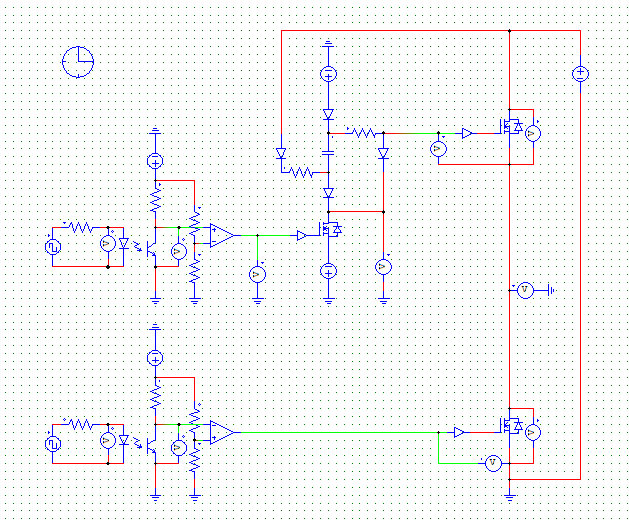
digitalWrite(10, HIGH);

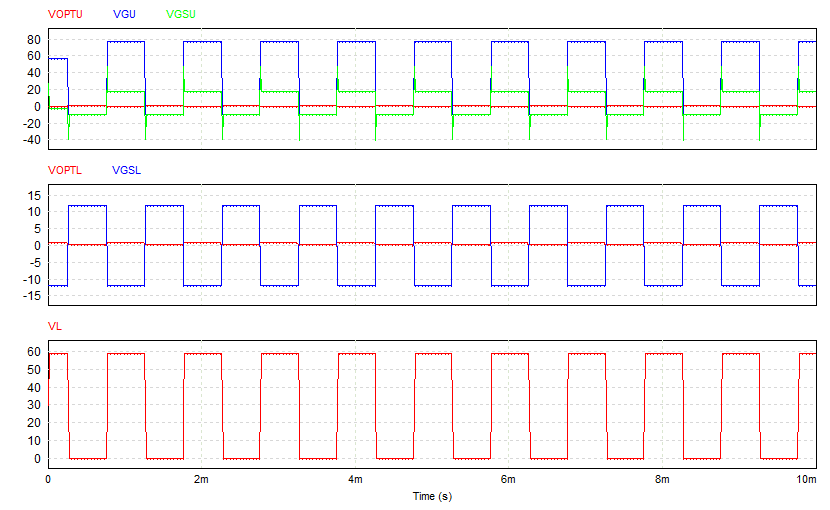
digitalWrite(11, LOW);

delayMicroseconds(delayTime/3);

}

## Inverter with Optical Isolation





# References