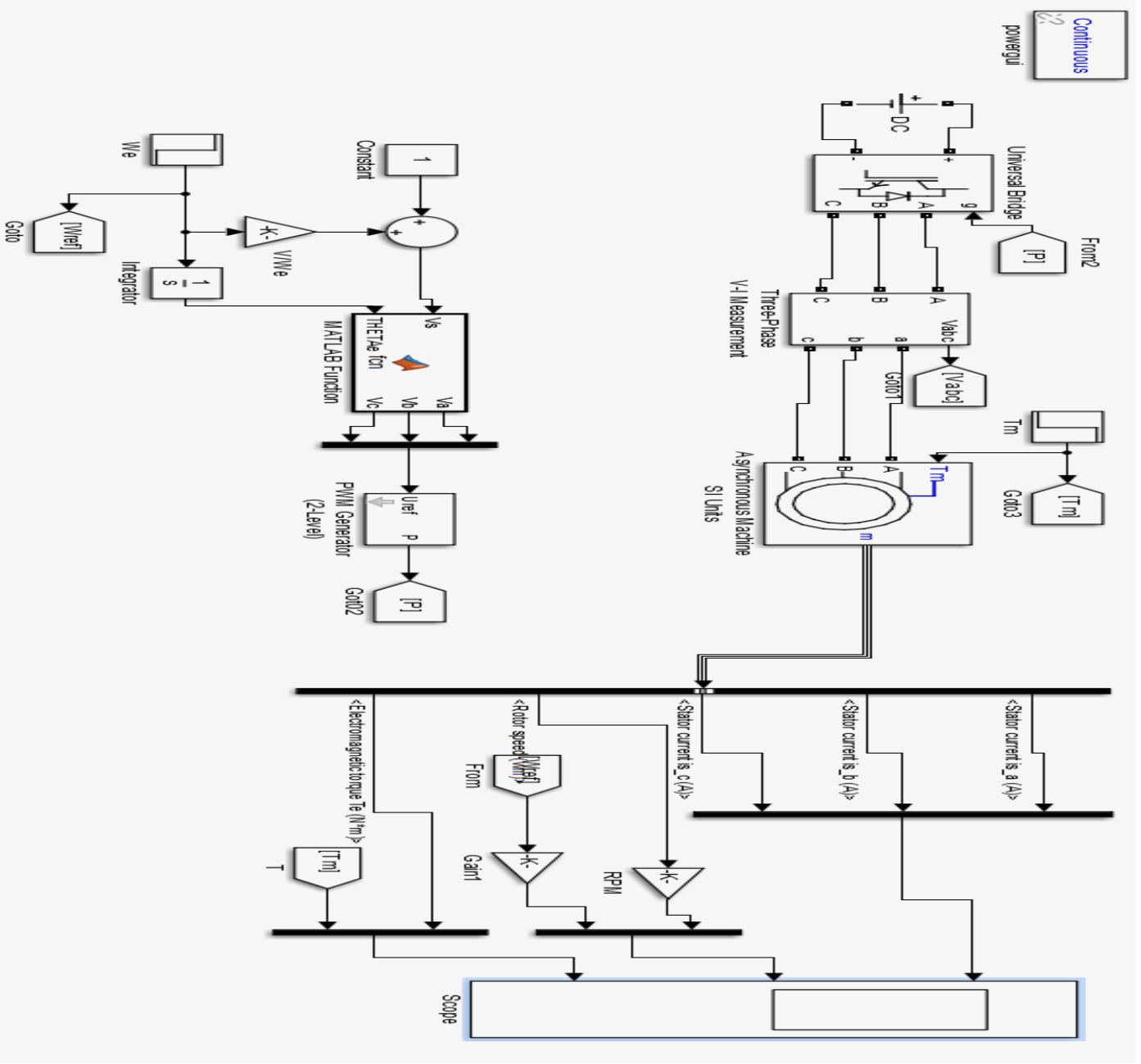
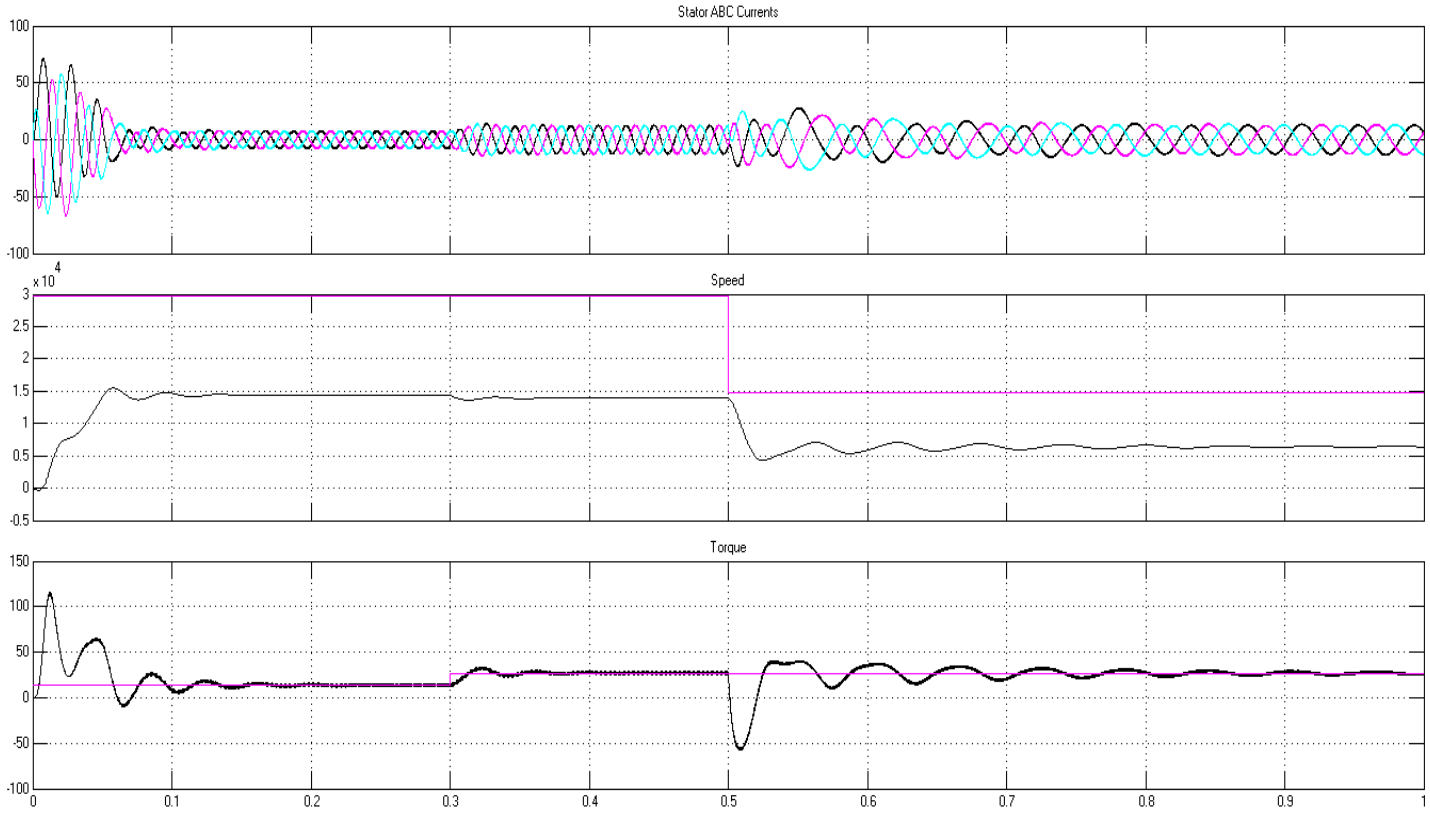
Tutorial - V/F Control of Induction Motor

1. V/F OPEN LOOP CONTROL

Simulink Model:

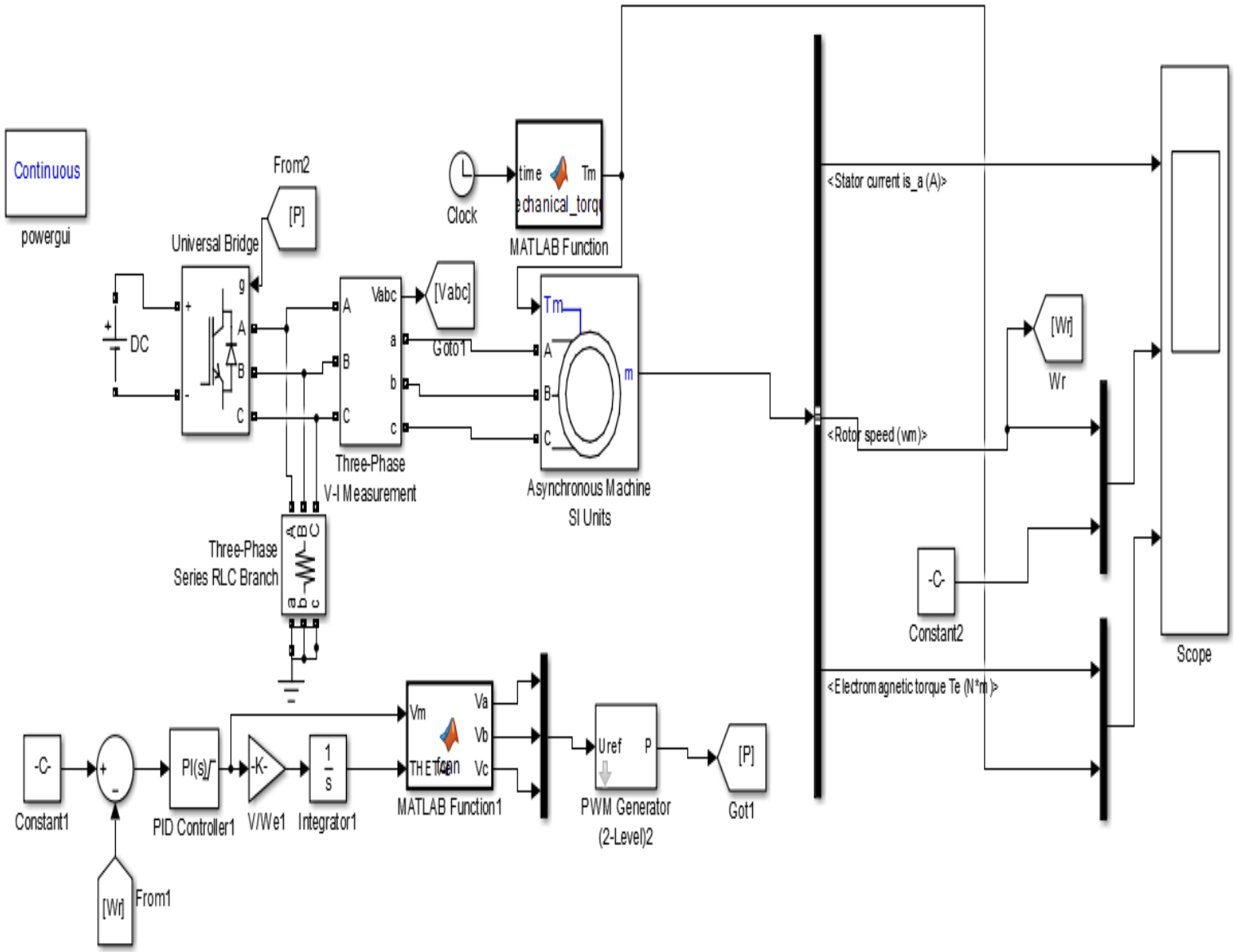


Output:

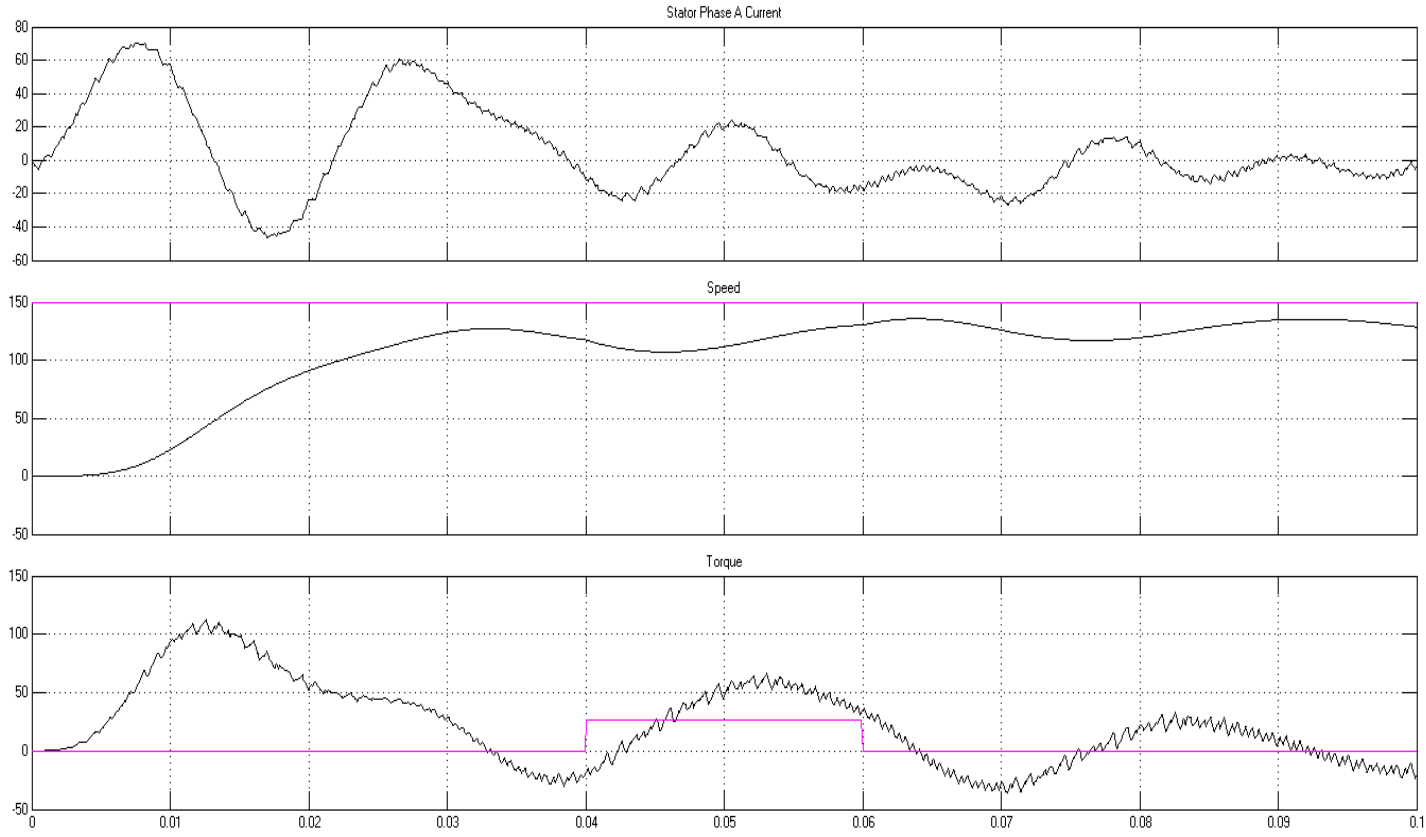

Stator ABC Currents
100
50
0
-50
-100
x 10^4
Speed
3
2.5
2
1.5
1
0.5
0
-0.5
Torque
150
100
50
0
-50
-100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

2. V/F CLOSED LOOP CONTROL

Simulink Model:


Continuous
powergui
From2
[P]
Universal Bridge
DC
g
A
B
C
Vabc
[Vabc]
Goto1
Three-Phase
V-I Measurement
Clock
time
Tm
echanical_torq
MATLAB Function
Tm
m
Asynchronous Machine
SI Units
Three-Phase
Series RLC Branch
<Stator current is_a (A)>
<Rotor speed (wm)>
<Electromagnetic torque Te (N*m)>
[Wr]
Wr
-C-
Constant2
Scope
-K-
Constant1
PI(s)
PID Controller1
V/We1
1
s
Integrator1
Vm
THETA
Va
Vb
Vc
MATLAB Function1
Uref
P
PWM Generator
(2-Level)2
[P]
Got1
[Wr]
From1

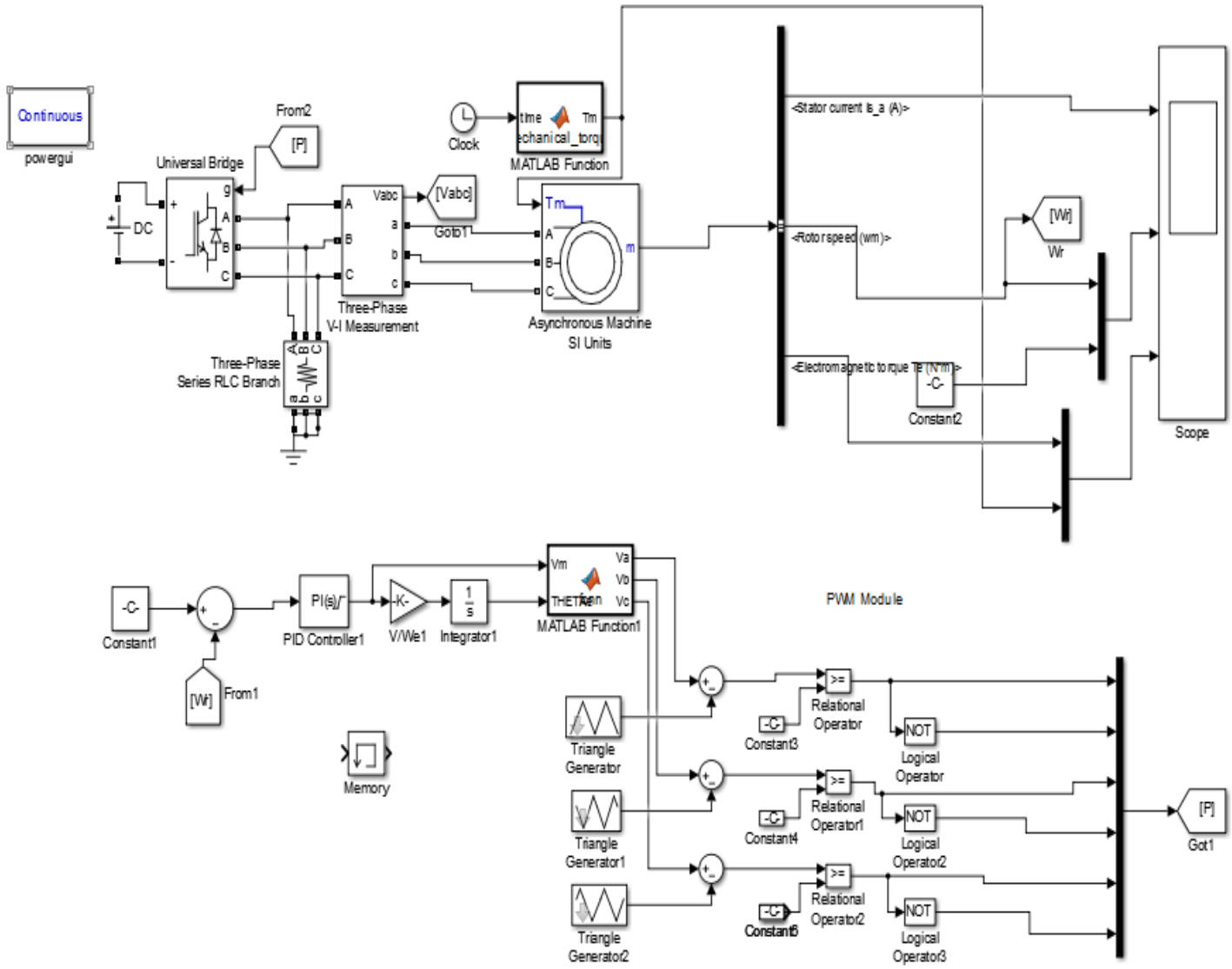
Output:


Stator Phase A Current
80
60
40
20
0
-20
-40
-60
Speed
150
100
50
0
-50
Torque
150
100
50
0
-50
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

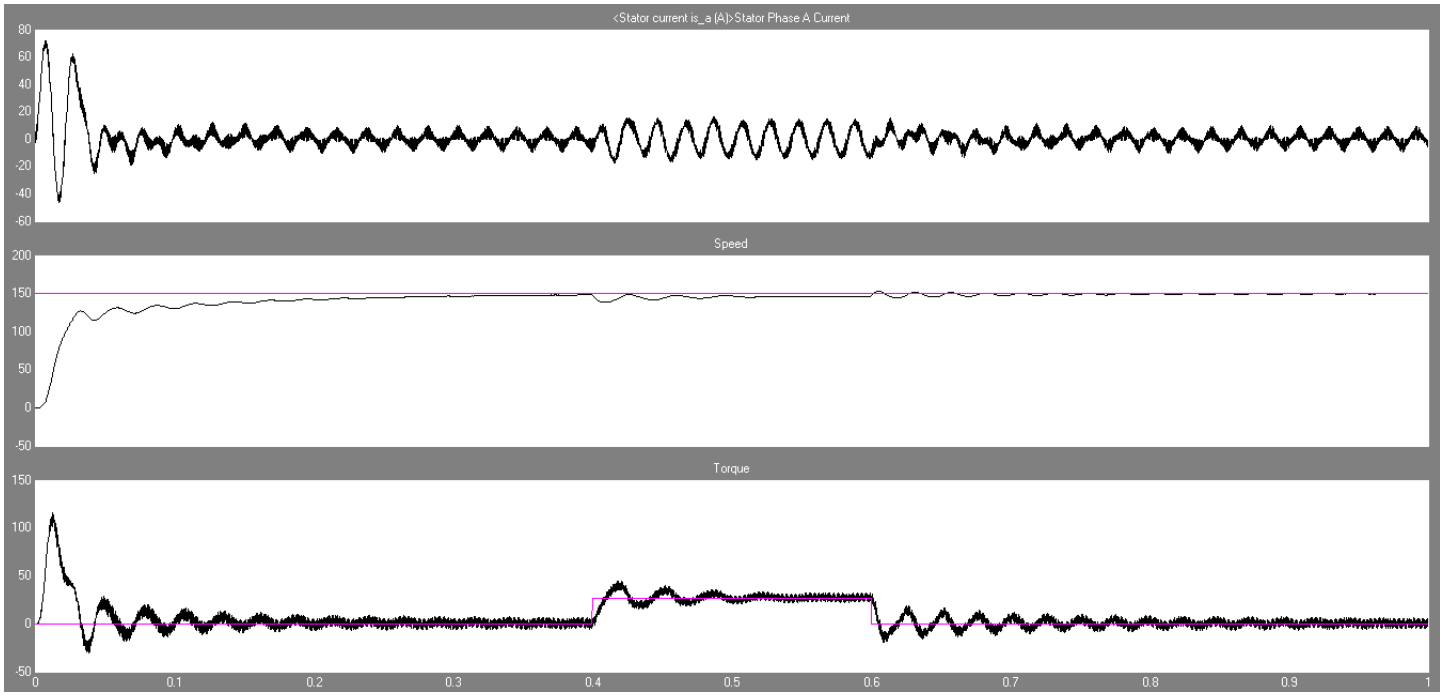
Tutorial - Induction Motor Control By PWM and SVM

1. IM CONTROL BY PWM

Simulink Model:



Output:


<Stator current is_a (A)>Stator Phase A Current
80
60
40
20
0
-20
-40
-60
Speed
200
150
100
50
0
-50
Torque
150
100
50
0
-50
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

2. IM CONTROL BY SVM

Simulink Model:

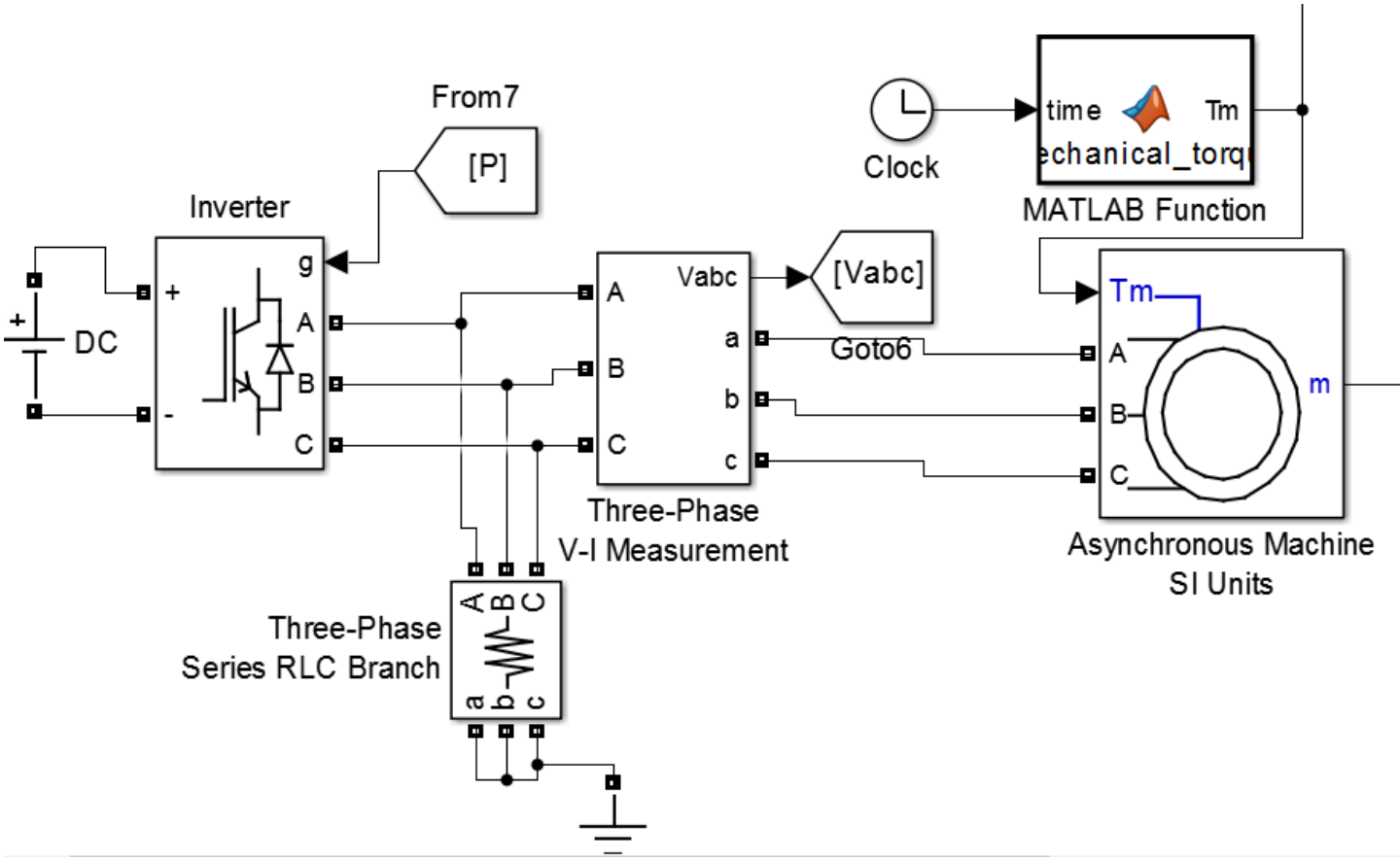


Figure 1IM with Inverter

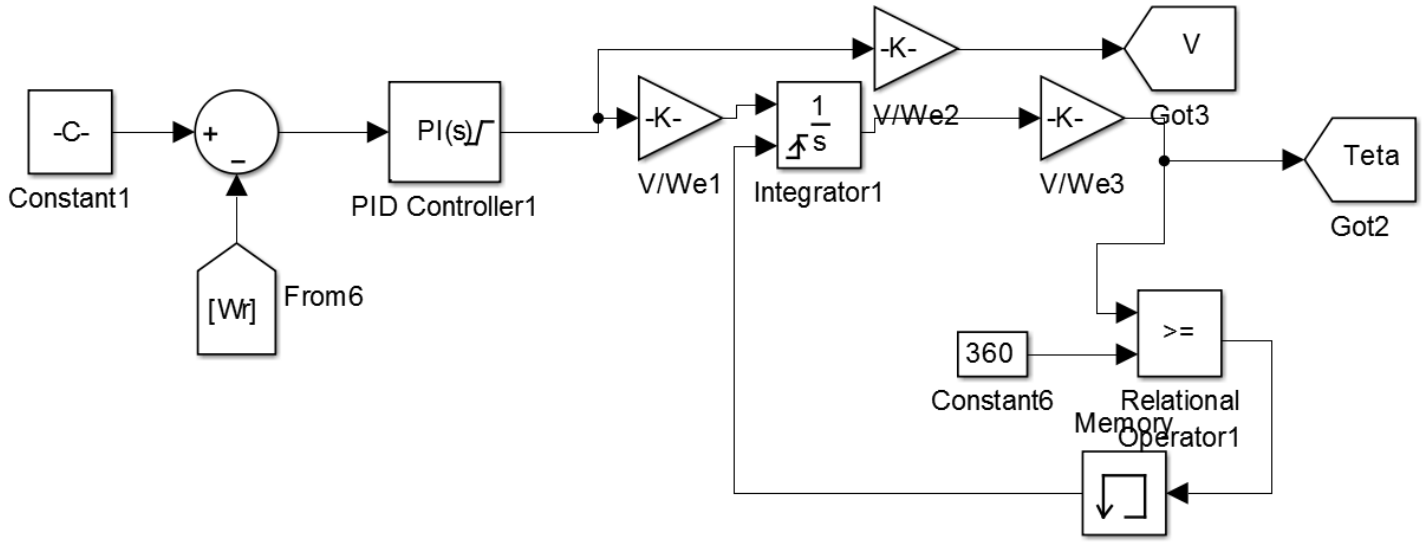


Figure 2Closed Loop Control Scheme

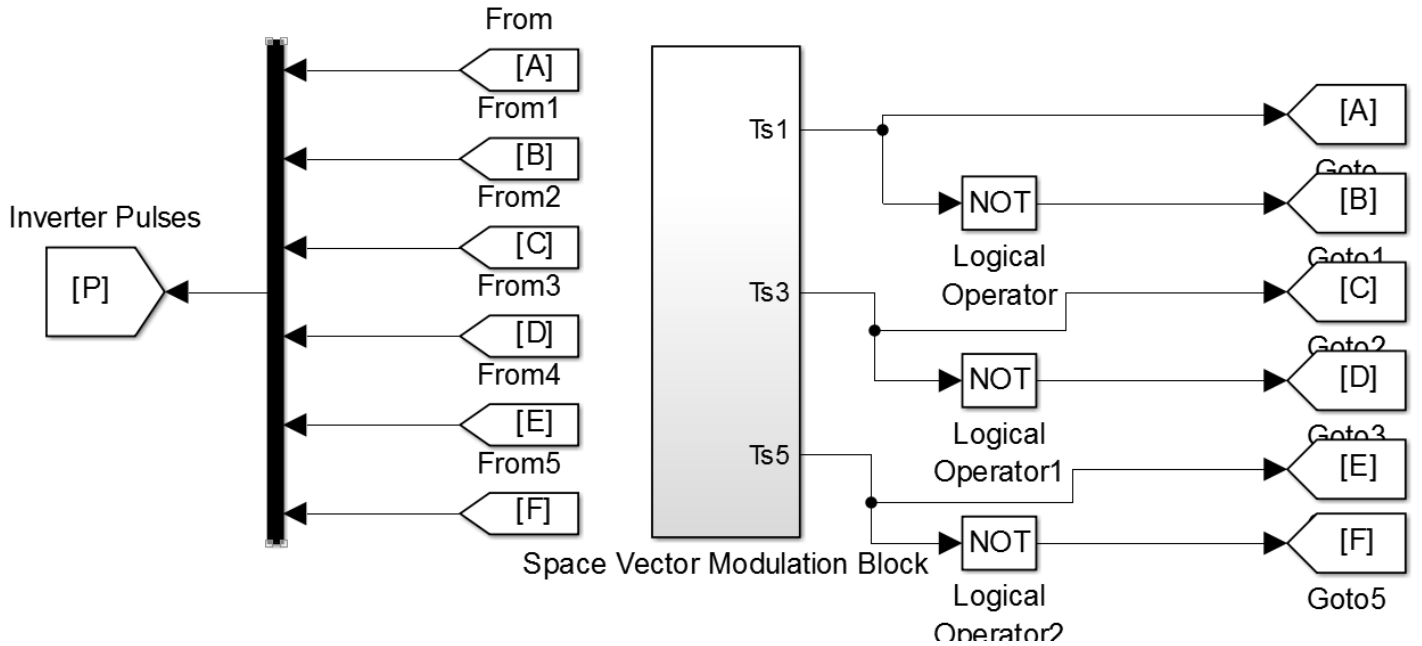


Figure 3Inverter Pulses Generation from SVM Block

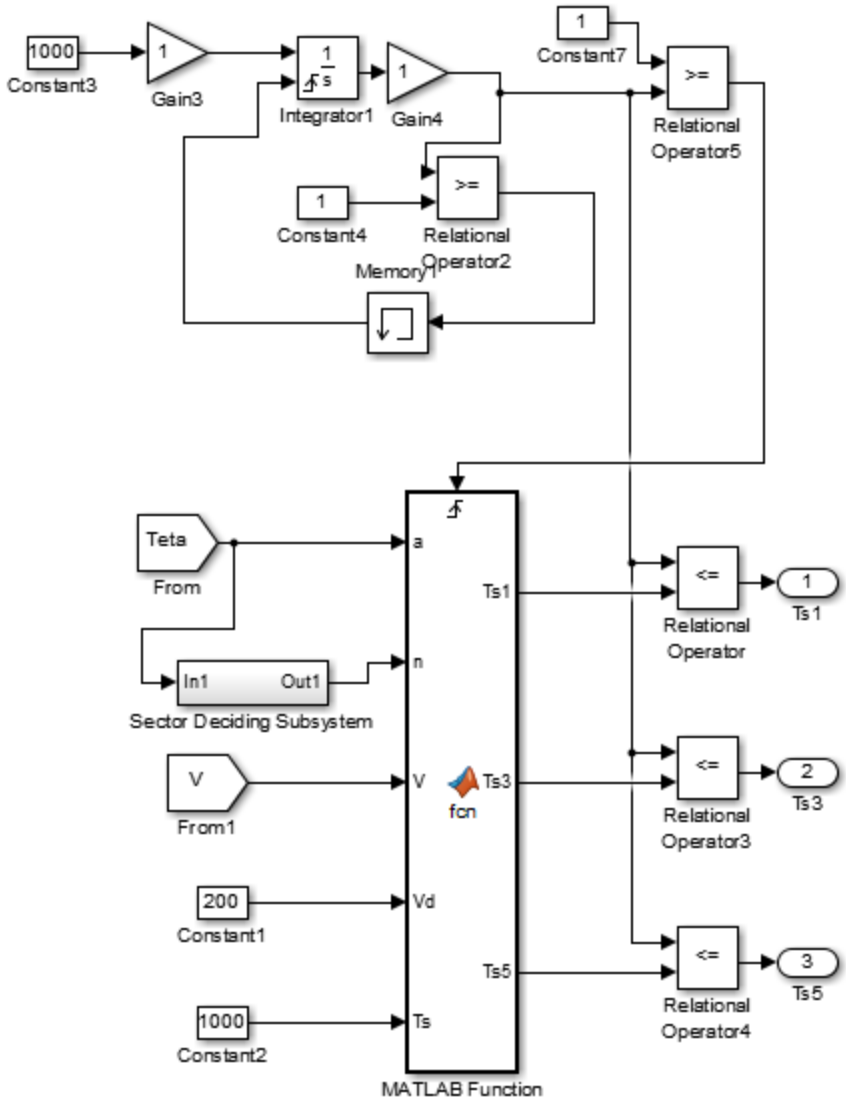


Figure 4 SVM Subsystem

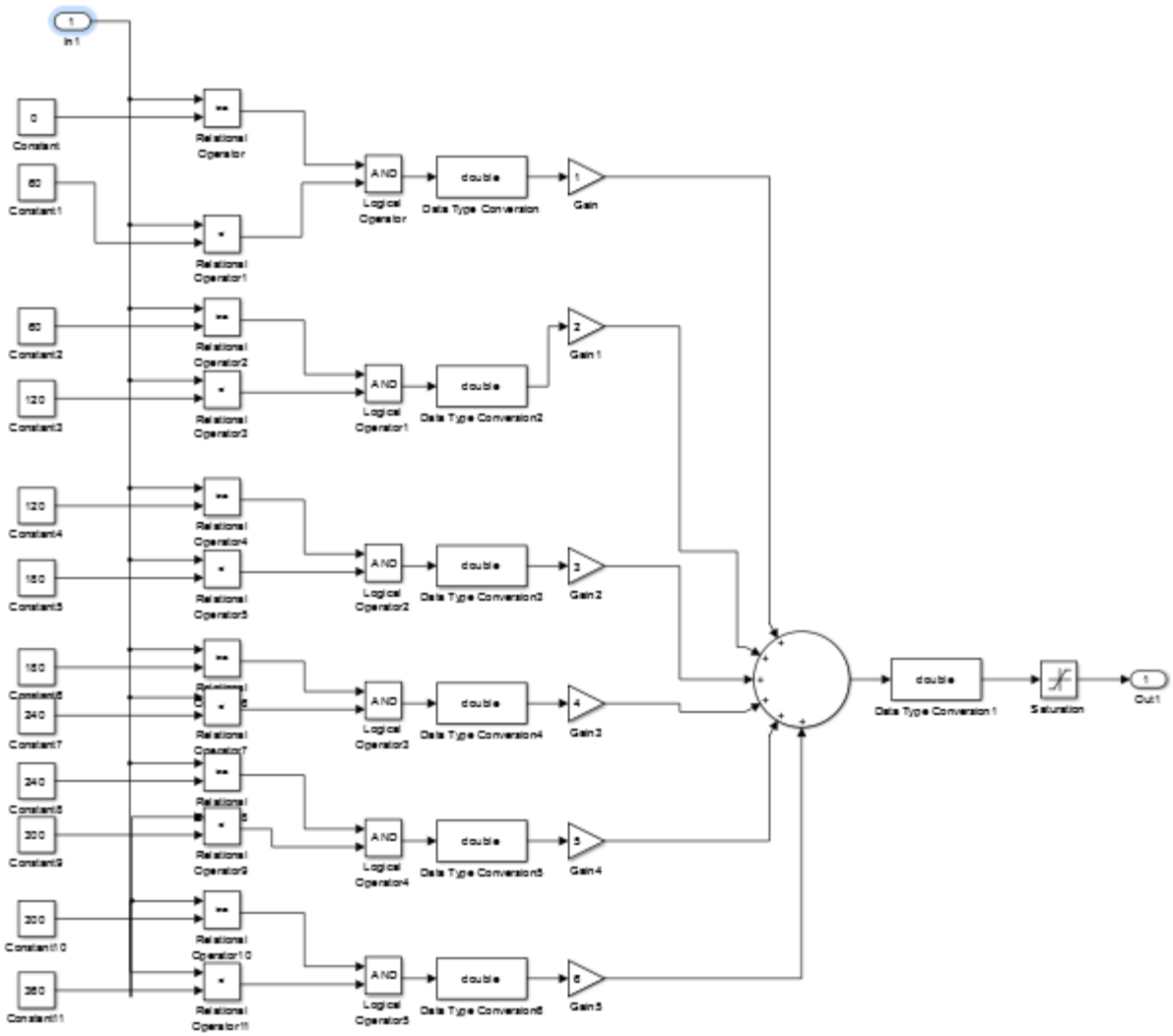


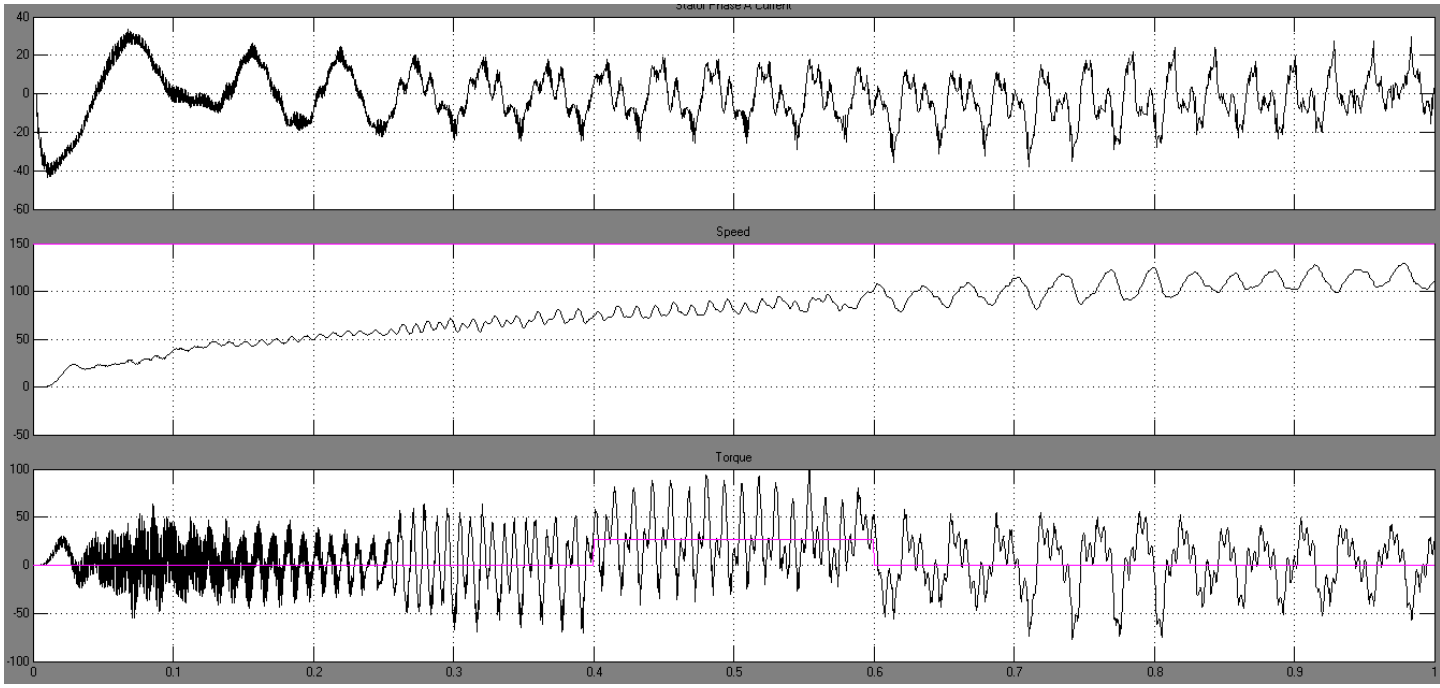
Figure 5Setor Deciding Subsystem

Matlab Program: To calculate OFF times for Inverter IGBT's

```
function [Ts1,Ts3,Ts5] = fcn(a,n,V,Vd,Ts)

a=a.*pi./180;
s=(3.^0.5).*(V/Vd).*Ts;
Ta=s.*sin((n.*pi./3)-a);
Tb=s.*sin(a-(n-1).*pi./3);
To=Ts-Ta-Tb;
Ts1=0;Ts3=0;Ts5=0;
switch n
    case 1
        Ts1=(Ts-(Ta+Tb+To./2))./Ts;
        Ts3=(Ts-(Tb+To./2))./Ts;
        Ts5=(Ts-(To./2))./Ts;
    case 2
```

```
        Ts1=(Ts-(Ta+To./2))./Ts;
        Ts3=(Ts-(Ta+Tb+To./2))./Ts;
        Ts5=(Ts-(To./2))./Ts;
    case 3
        Ts1=(Ts-(To./2))./Ts;
        Ts3=(Ts-(Ta+Tb+To./2))./Ts;
        Ts5=(Ts-(Tb+To./2))./Ts;
    case 4
        Ts1=(Ts-(To./2))./Ts;
        Ts3=(Ts-(Ta+To./2))./Ts;
        Ts5=(Ts-(Ta+Tb+To./2))./Ts;
    case 5
        Ts1=(Ts-(Tb+To./2))./Ts;
        Ts3=(Ts-(To./2))./Ts;
        Ts5=(Ts-(Ta+Tb+To./2))./Ts;
    case 6
        Ts1=(Ts-(Ta+Tb+To./2))./Ts;
        Ts3=(Ts-(To./2))./Ts;
        Ts5=(Ts-(Ta+To./2))./Ts;
end
return;
```

Output:



Tutorial - Direct Rotor Flux Oriented Control For Induction Motor

Simulink Model:

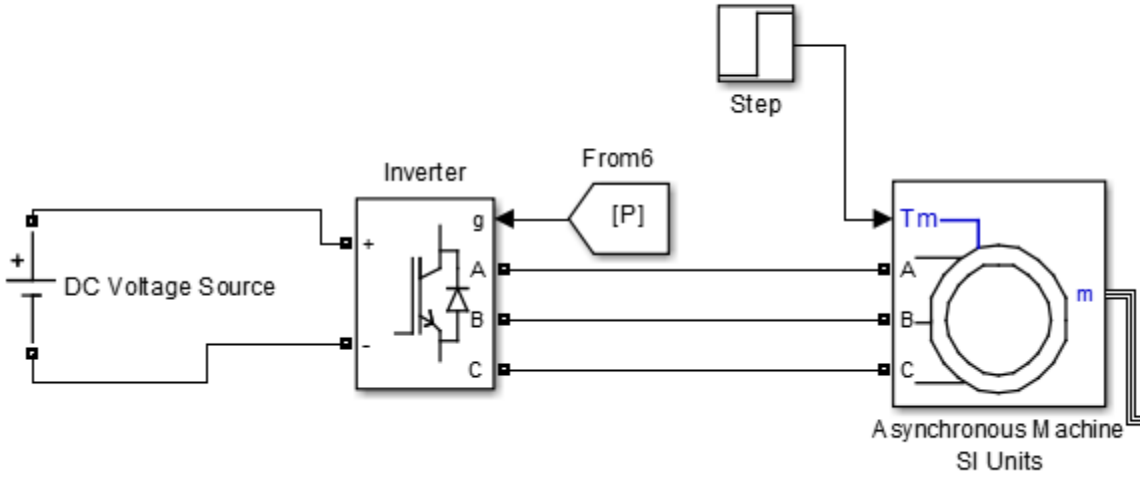


Figure 6IM with Inverter

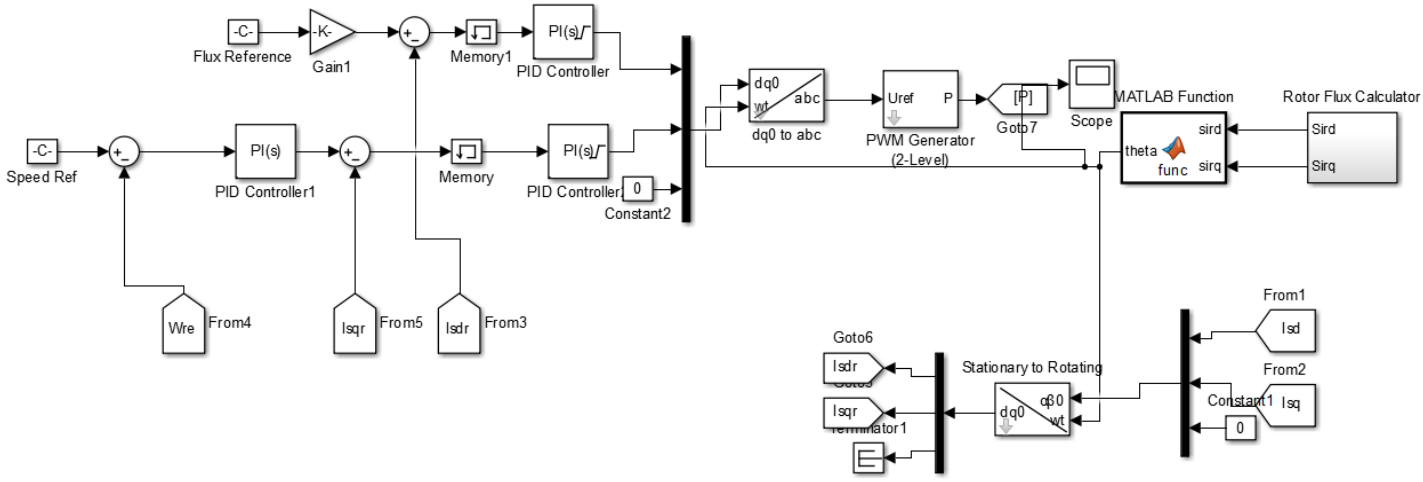


Figure 7 DRFO Control Scheme

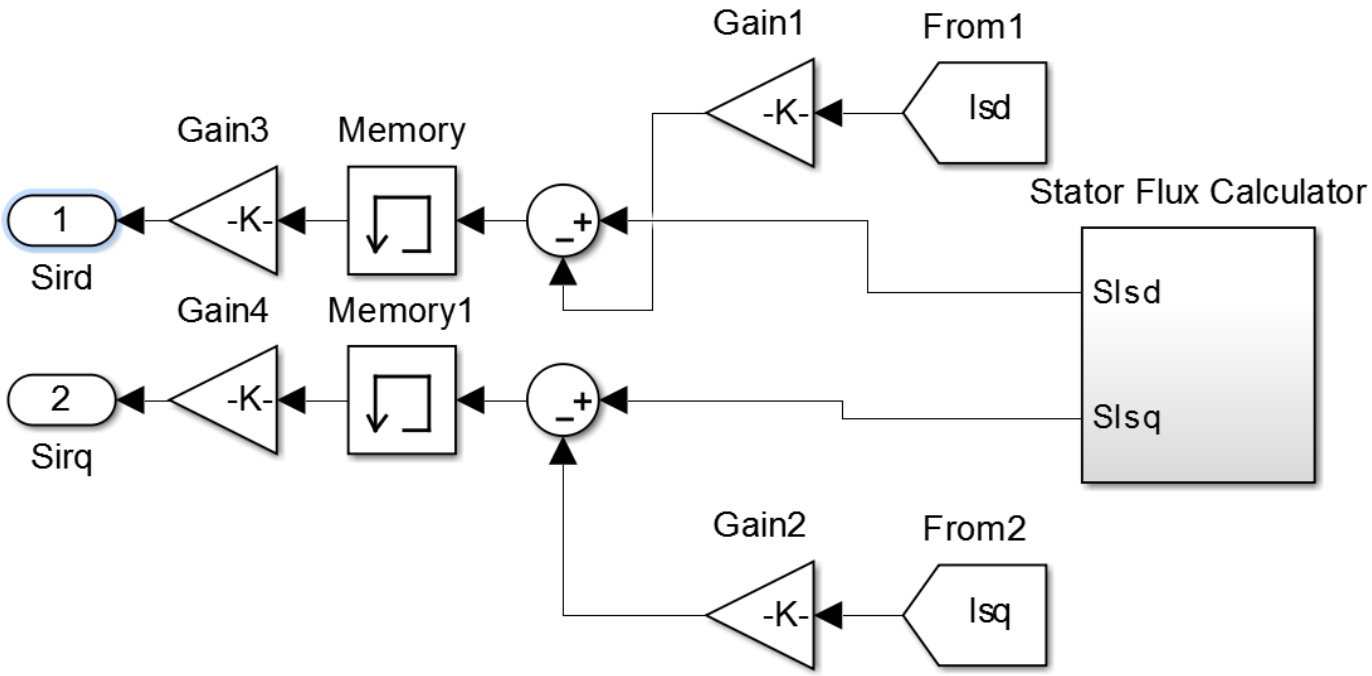


Figure 8Rotor Flux Calculator Subsystem

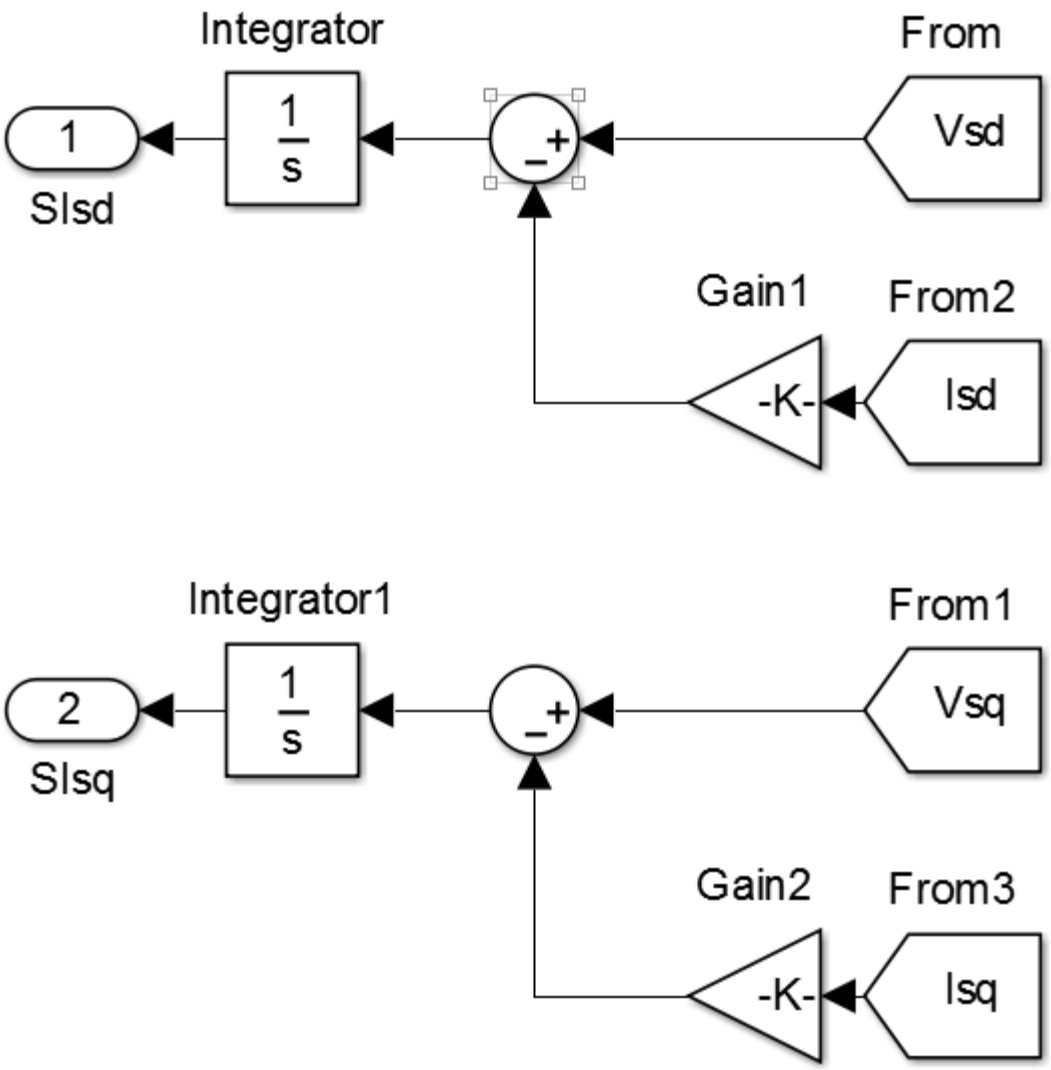
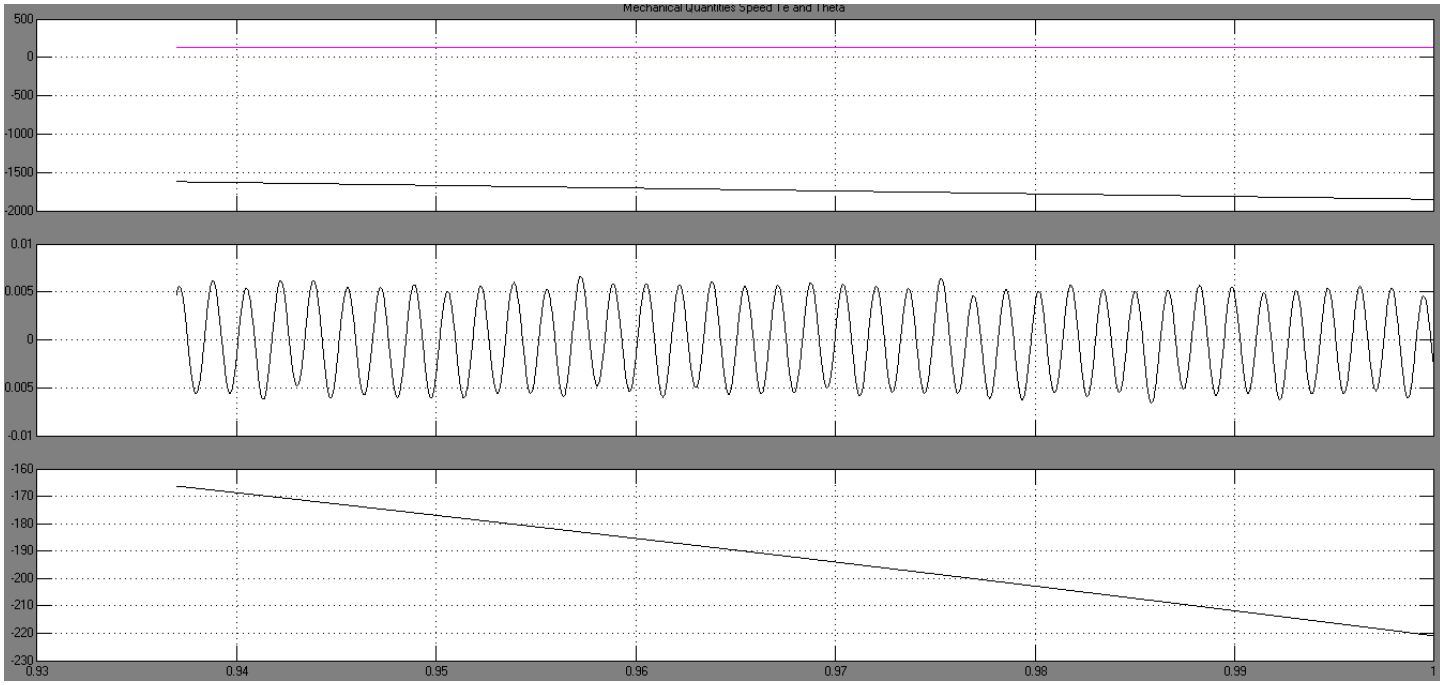
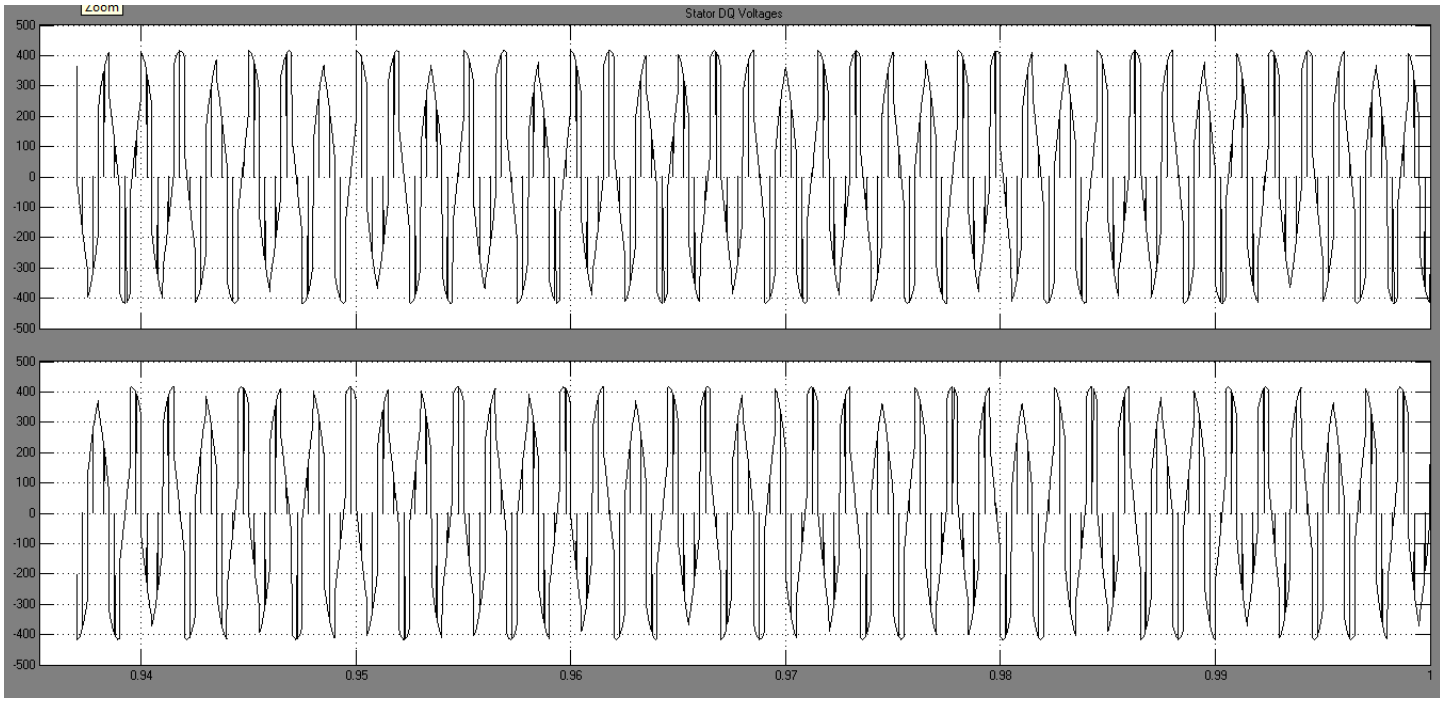
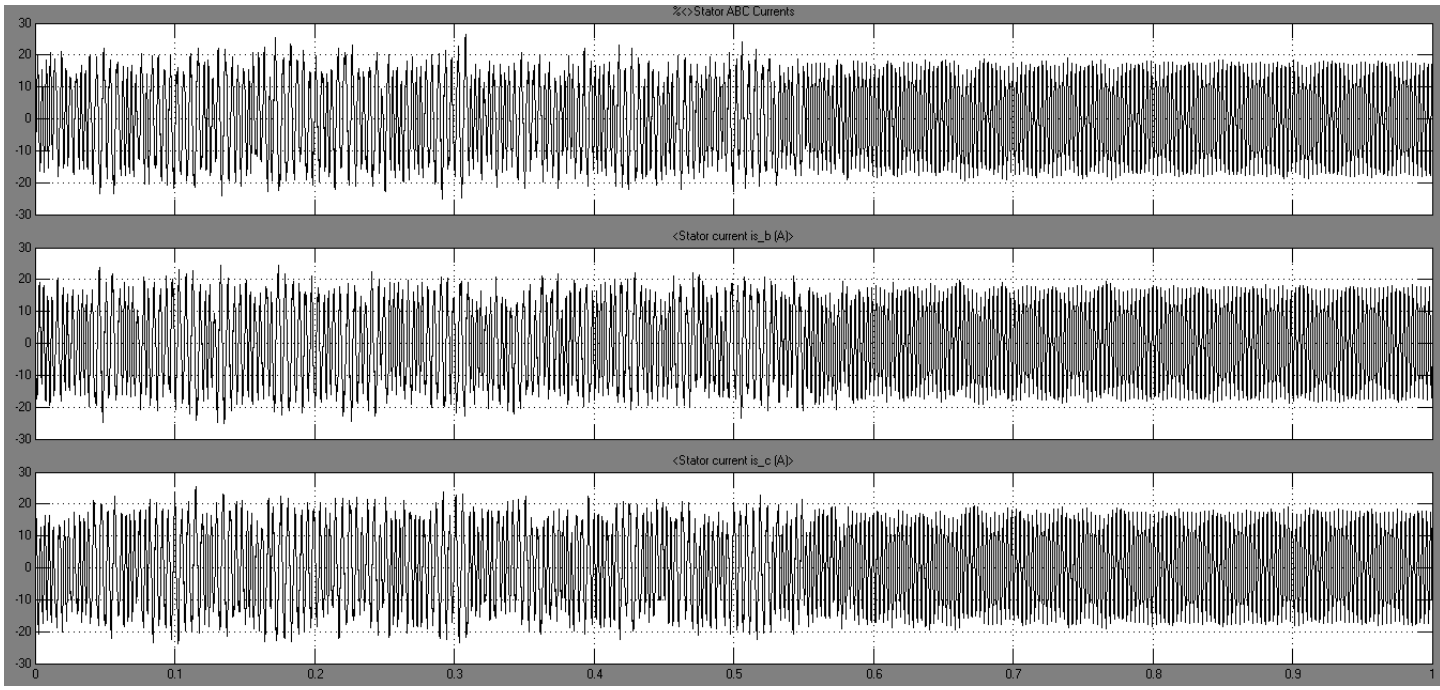


Figure 9 Stator Flux Calculator Subsystem

Outputs:


Mechanical Quantities Speed Te and Theta
500
0
-500
-1000
-1500
-2000
0.01
0.005
0
-0.005
-0.01
-160
-170
-180
-190
-200
-210
-220
-230
0.93
0.94
0.95
0.96
0.97
0.98
0.99
1


Zoom
Stator DQ Voltages
500
400
300
200
100
0
-100
-200
-300
-400
-500
0.94
0.95
0.96
0.97
0.98
0.99
1



Tutorial - Direct Torque Control

Simulink Model:

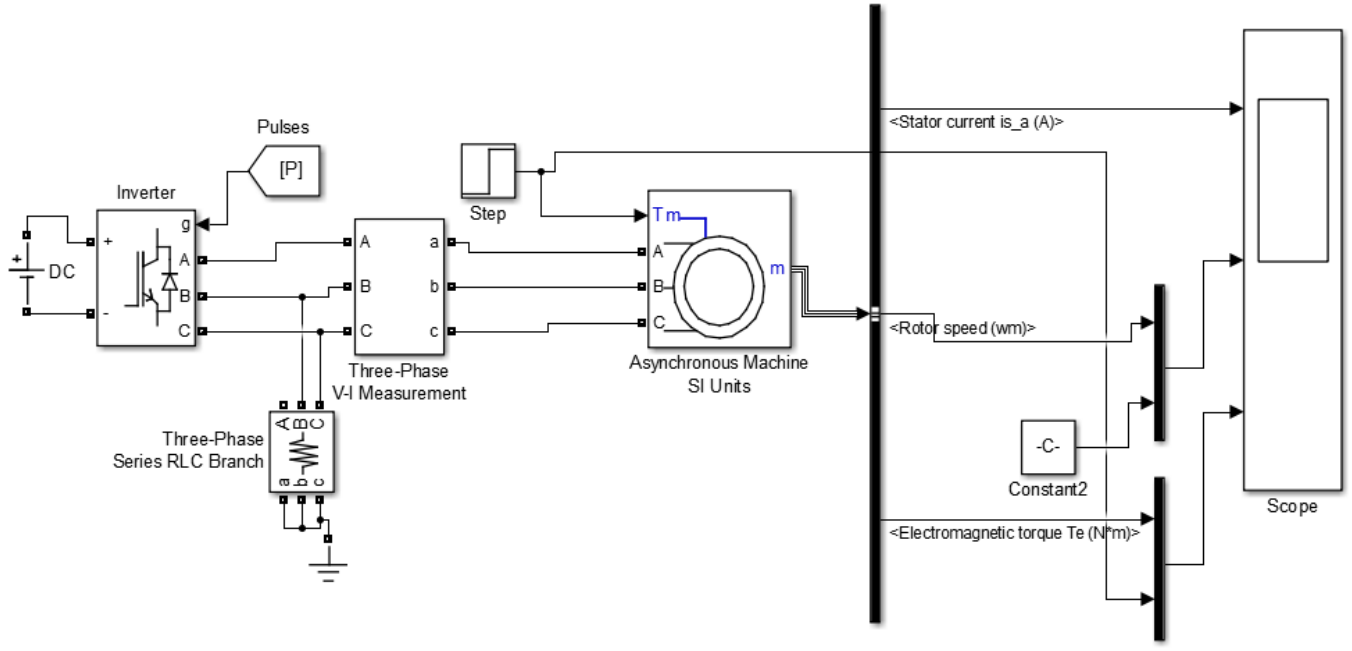


Figure 10 Induction Motor with Inverter

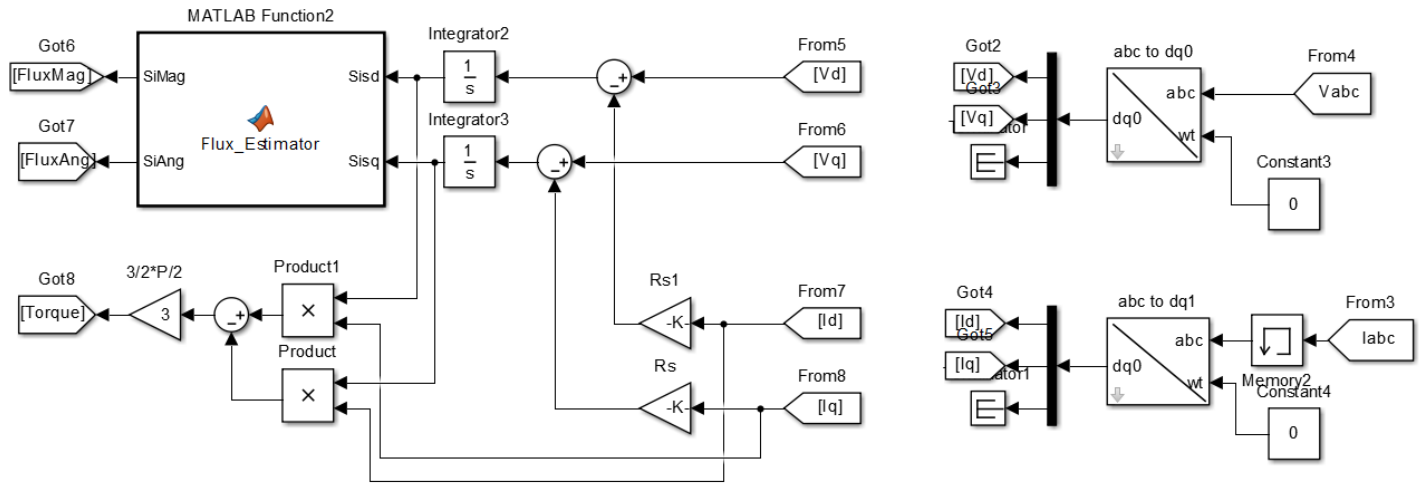


Figure 11 Stator Flux and Torque Calculations

Matlab Program: Flux Esimator

```
function [SiMag,SiAng] = Flux_Estimator(Sisd,Sisq)
 SiMag=((Sisd)^(2)+(Sisq)^(2))^(0.5);
 x=atan2(Sisq,Sisd);
 if(x>=0)
    SiAng=x*(180/(2*pi));
 else
    SiAng=x*(180/(2*pi))+360;
 end
```

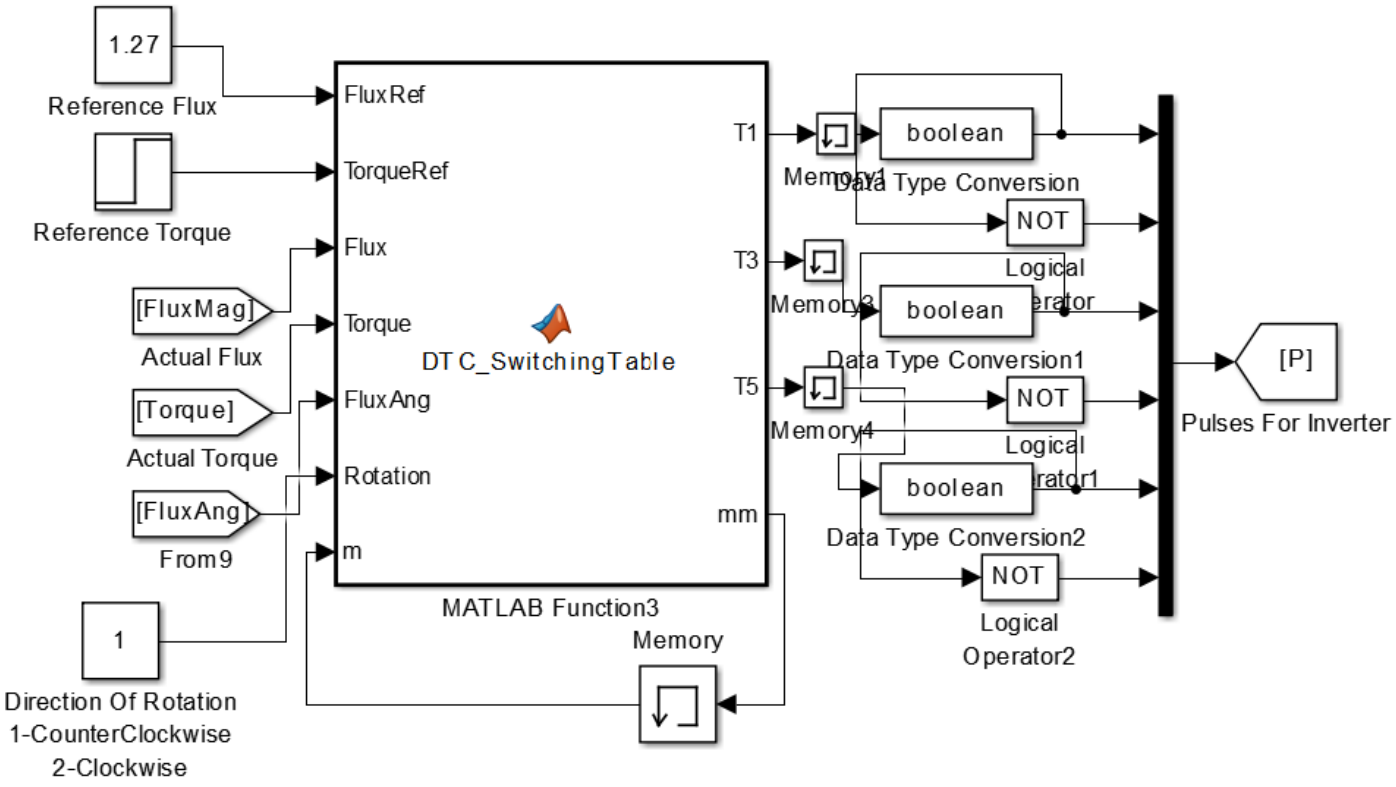


Figure 12DTC Voltage Vector Lookup Table

Matlab Program: DTC Switching Table Program

```
function [T1,T3,T5,mm] =
DTC_SwitchingTable(FluxRef,TorqueRef,Flux,Torque,FluxAng,Rotation,m)

T1=0;
T3=0;
T5=0;

DelF=0.0025;% Hysteresis Width for Flux
DelT=0.025;% Hysteresis Width for Torque

Hf=0;%Initializing Hysteresis Controller Output For Flux
Ht=0;%Initializing Hysteresis Controller Output For Torque
S=0;%Initializing DTC Space Vector Sector
mm=m;
% Flux Two Level Hysteresis Band %
%-------------------------------------------------------------------------%
if(Flux<=(FluxRef-DelF))
    Hf=1;
    mm=Hf;
end
if(mm==1&&(Flux>(FluxRef-DelF)&&Flux<(FluxRef+DelF)))
    Hf=1;
    mm=Hf;
end
if(Flux>=(FluxRef+DelF))
```

```
    Hf=0;
    mm=Hf;
end
if(mm==0&&(Flux>(FluxRef-DelF)&&Flux<(FluxRef+DelF)))
    Hf=0;
    mm=Hf;
end

% Torque Three Level Hysteresis Band %
%-------------------------------------------------------------------------%
if(Torque<=(TorqueRef-DelT))
    Ht=1;
end
if(Torque>(TorqueRef-DelT)&&Torque<(TorqueRef+DelT))
    Ht=0;
end
if(Torque>=(TorqueRef+DelT))
    Ht=-1;
end

% DTC Sector Prediction %
%-------------------------------------------------------------------------%
if(FluxAng>=330&&FluxAng<30)
    S=1;
end
if(FluxAng>=30&&FluxAng<90)
    S=2;
end
if(FluxAng>=90&&FluxAng<150)
    S=3;
end
if(FluxAng>=150&&FluxAng<210)
    S=4;
end
if(FluxAng>=210&&FluxAng<270)
    S=5;
end
if(FluxAng>=270&&FluxAng<330)
    S=6;
end

% Voltage Vector Synthesis %
%-------------------------------------------------------------------------%
if(Rotation==2)% Clockwise Rotation
%-------------------------------------------------------------------------%
    if(Hf==1&&Ht==1&&S==1)
        T1=1;
        T3=0;
        T5=1;
    end
    if(Hf==1&&Ht==1&&S==2)
      T1=0;
      T3=0;
      T5=1;
    end
    if(Hf==1&&Ht==1&&S==3)
```

```
      T1=0;
      T3=1;
      T5=1;
    end
    if(Hf==1&&Ht==1&&S==4)
      T1=0;
      T3=1;
      T5=0;
    end
    if(Hf==1&&Ht==1&&S==5)
      T1=1;
      T3=1;
      T5=0;
    end
    if(Hf==1&&Ht==1&&S==6)
      T1=1;
      T3=0;
      T5=0;
    end

%-------------------------------------------------------------------------%
    if(Hf==1&&Ht==0&&S==1)
        T1=1;
        T3=1;
        T5=1;
    end
    if(Hf==1&&Ht==0&&S==2)
      T1=0;
      T3=0;
      T5=0;
    end
    if(Hf==1&&Ht==0&&S==3)
      T1=1;
      T3=1;
      T5=1;
    end
    if(Hf==1&&Ht==0&&S==4)
      T1=0;
      T3=0;
      T5=0;
    end
    if(Hf==1&&Ht==0&&S==5)
      T1=1;
      T3=1;
      T5=1;
    end
    if(Hf==1&&Ht==0&&S==6)
      T1=0;
      T3=0;
      T5=0;
    end
%-------------------------------------------------------------------------%
    if(Hf==1&&Ht==-1&&S==1)
        T1=1;
        T3=1;
        T5=0;
    end
```

```
    if(Hf==1&&Ht==-1&&S==2)
      T1=1;
      T3=0;
      T5=0;
    end
    if(Hf==1&&Ht==-1&&S==3)
      T1=1;
      T3=0;
      T5=1;
    end
    if(Hf==1&&Ht==-1&&S==4)
      T1=0;
      T3=0;
      T5=1;
    end
    if(Hf==1&&Ht==-1&&S==5)
      T1=0;
      T3=1;
      T5=1;
    end
    if(Hf==1&&Ht==-1&&S==6)
      T1=0;
      T3=1;
      T5=0;
    end

%-------------------------------------------------------------------------%

     if(Hf==0&&Ht==1&&S==1)
        T1=0;
        T3=0;
        T5=1;
    end
    if(Hf==0&&Ht==1&&S==2)
      T1=0;
      T3=1;
      T5=1;
    end
    if(Hf==0&&Ht==1&&S==3)
      T1=0;
      T3=1;
      T5=0;
    end
    if(Hf==0&&Ht==1&&S==4)
      T1=1;
      T3=1;
      T5=0;
    end
    if(Hf==0&&Ht==1&&S==5)
      T1=1;
      T3=0;
      T5=0;
    end
    if(Hf==0&&Ht==1&&S==6)
      T1=1;
      T3=0;
```

```
      T5=1;
    end
%-------------------------------------------------------------------------%

    if(Hf==0&&Ht==0&&S==1)
        T1=0;
        T3=0;
        T5=0;
    end
    if(Hf==0&&Ht==0&&S==2)
      T1=1;
      T3=1;
      T5=1;
    end
    if(Hf==0&&Ht==0&&S==3)
      T1=0;
      T3=0;
      T5=0;
    end
    if(Hf==0&&Ht==0&&S==4)
      T1=1;
      T3=1;
      T5=1;
    end
    if(Hf==0&&Ht==0&&S==5)
      T1=0;
      T3=0;
      T5=0;
    end
    if(Hf==0&&Ht==0&&S==6)
      T1=1;
      T3=1;
      T5=1;
    end
  %-------------------------------------------------------------------------%

    if(Hf==0&&Ht==-1&&S==1)
        T1=0;
        T3=1;
        T5=0;
    end
    if(Hf==0&&Ht==-1&&S==2)
      T1=1;
      T3=1;
      T5=0;
    end
    if(Hf==0&&Ht==-1&&S==3)
      T1=1;
      T3=0;
      T5=0;
    end
    if(Hf==0&&Ht==-1&&S==4)
      T1=1;
      T3=0;
      T5=1;
    end
```

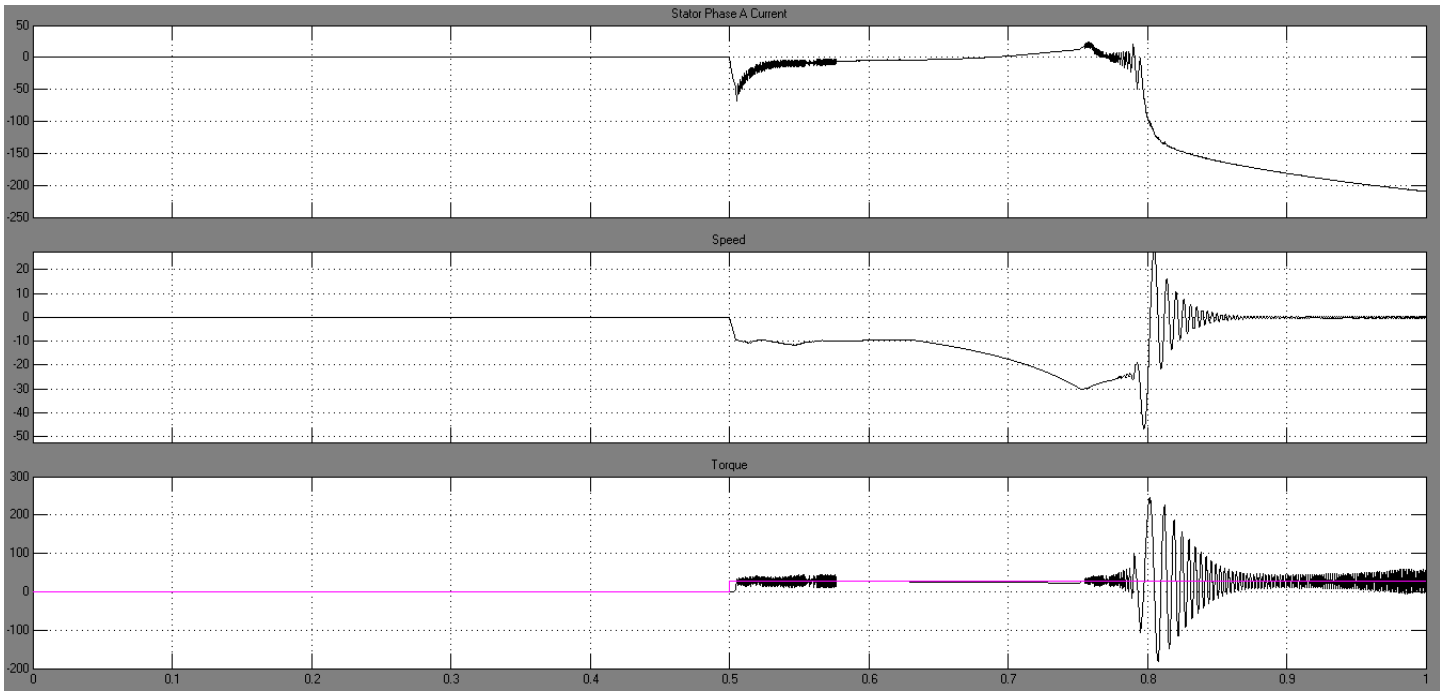
```
    if(Hf==0&&Ht==-1&&S==5)
      T1=0;
      T3=0;
      T5=1;
    end
    if(Hf==0&&Ht==-1&&S==6)
      T1=0;
      T3=1;
      T5=1;
    end
end

%-------------------------------------------------------------------------%
if(Rotation==1)% Counter-Clockwise Rotation
%-------------------------------------------------------------------------%
    if(Hf==1&&Ht==1&&S==1)
        T1=1;
        T3=1;
        T5=0;
    end
    if(Hf==1&&Ht==1&&S==2)
      T1=0;
      T3=1;
      T5=0;
    end
    if(Hf==1&&Ht==1&&S==3)
      T1=0;
      T3=1;
      T5=1;
    end
    if(Hf==1&&Ht==1&&S==4)
      T1=0;
      T3=0;
      T5=1;
    end
    if(Hf==1&&Ht==1&&S==5)
      T1=1;
      T3=0;
      T5=1;
    end
    if(Hf==1&&Ht==1&&S==6)
      T1=1;
      T3=0;
      T5=0;
    end

%-------------------------------------------------------------------------%
    if(Hf==1&&Ht==0&&S==1)
        T1=1;
        T3=1;
        T5=1;
    end
    if(Hf==1&&Ht==0&&S==2)
      T1=0;
      T3=0;
      T5=0;
```

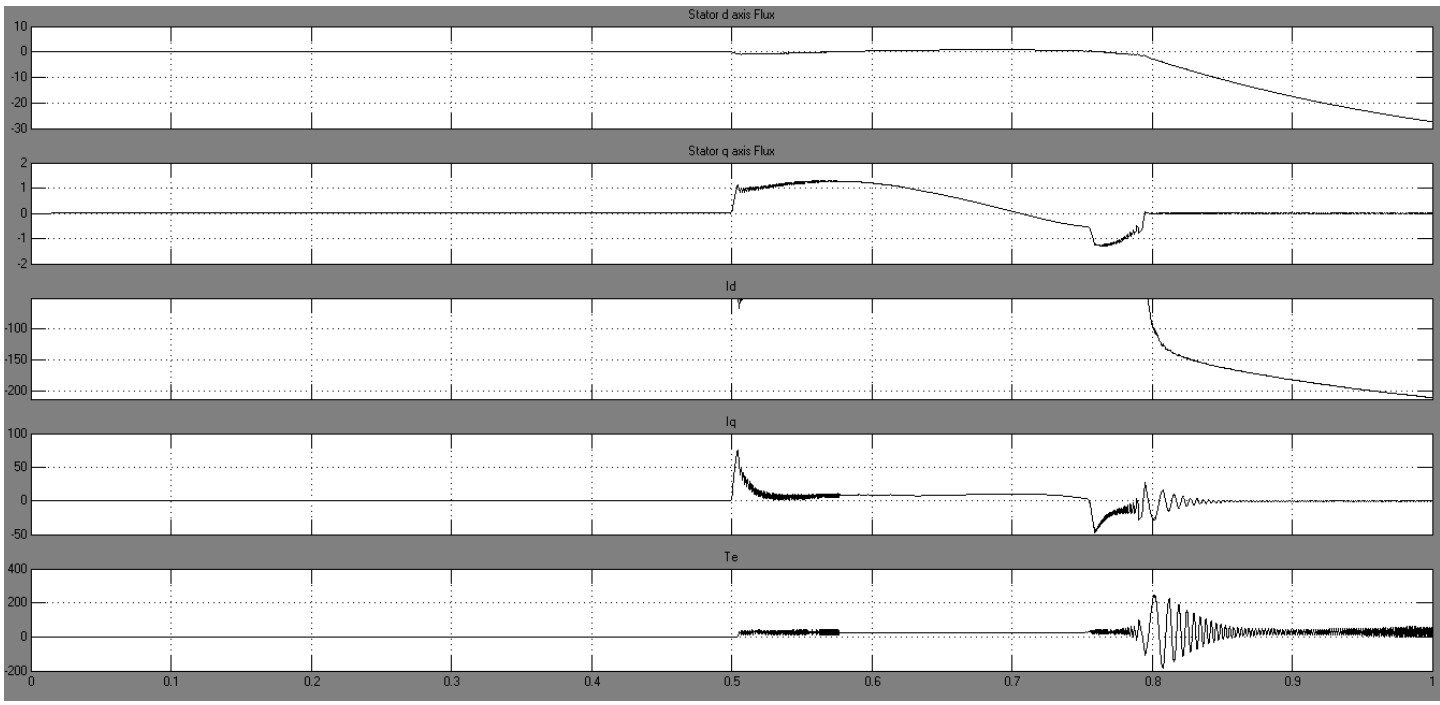
```
    end
    if(Hf==1&&Ht==0&&S==3)
      T1=1;
      T3=1;
      T5=1;
    end
    if(Hf==1&&Ht==0&&S==4)
      T1=0;
      T3=0;
      T5=0;
    end
    if(Hf==1&&Ht==0&&S==5)
      T1=1;
      T3=1;
      T5=1;
    end
    if(Hf==1&&Ht==0&&S==6)
      T1=0;
      T3=0;
      T5=0;
    end
%-------------------------------------------------------------------------%
    if(Hf==1&&Ht==-1&&S==1)
        T1=1;
        T3=0;
        T5=1;
    end
    if(Hf==1&&Ht==-1&&S==2)
      T1=1;
      T3=0;
      T5=0;
    end
    if(Hf==1&&Ht==-1&&S==3)
      T1=1;
      T3=1;
      T5=0;
    end
    if(Hf==1&&Ht==-1&&S==4)
      T1=0;
      T3=1;
      T5=0;
    end
    if(Hf==1&&Ht==-1&&S==5)
      T1=0;
      T3=1;
      T5=1;
    end
    if(Hf==1&&Ht==-1&&S==6)
      T1=0;
      T3=0;
      T5=1;
    end

%-------------------------------------------------------------------------%

     if(Hf==0&&Ht==1&&S==1)
```

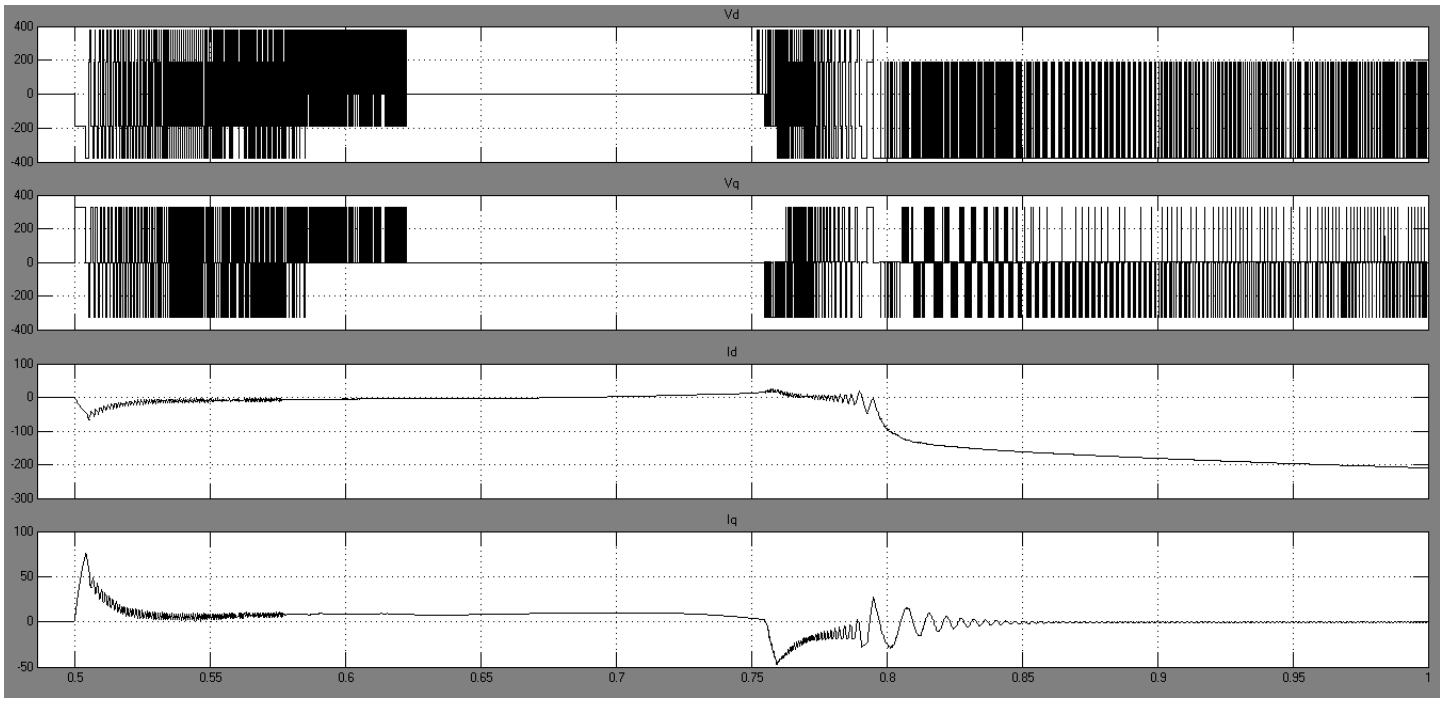
```
        T1=0;
        T3=1;
        T5=0;
    end
    if(Hf==0&&Ht==1&&S==2)
      T1=0;
      T3=1;
      T5=1;
    end
    if(Hf==0&&Ht==1&&S==3)
      T1=0;
      T3=0;
      T5=1;
    end
    if(Hf==0&&Ht==1&&S==4)
      T1=1;
      T3=0;
      T5=1;
    end
    if(Hf==0&&Ht==1&&S==5)
      T1=1;
      T3=0;
      T5=0;
    end
    if(Hf==0&&Ht==1&&S==6)
      T1=1;
      T3=1;
      T5=0;
    end
%-------------------------------------------------------------------------%

    if(Hf==0&&Ht==0&&S==1)
        T1=0;
        T3=0;
        T5=0;
    end
    if(Hf==0&&Ht==0&&S==2)
      T1=1;
      T3=1;
      T5=1;
    end
    if(Hf==0&&Ht==0&&S==3)
      T1=0;
      T3=0;
      T5=0;
    end
    if(Hf==0&&Ht==0&&S==4)
      T1=1;
      T3=1;
      T5=1;
    end
    if(Hf==0&&Ht==0&&S==5)
      T1=0;
      T3=0;
      T5=0;
    end
    if(Hf==0&&Ht==0&&S==6)
```

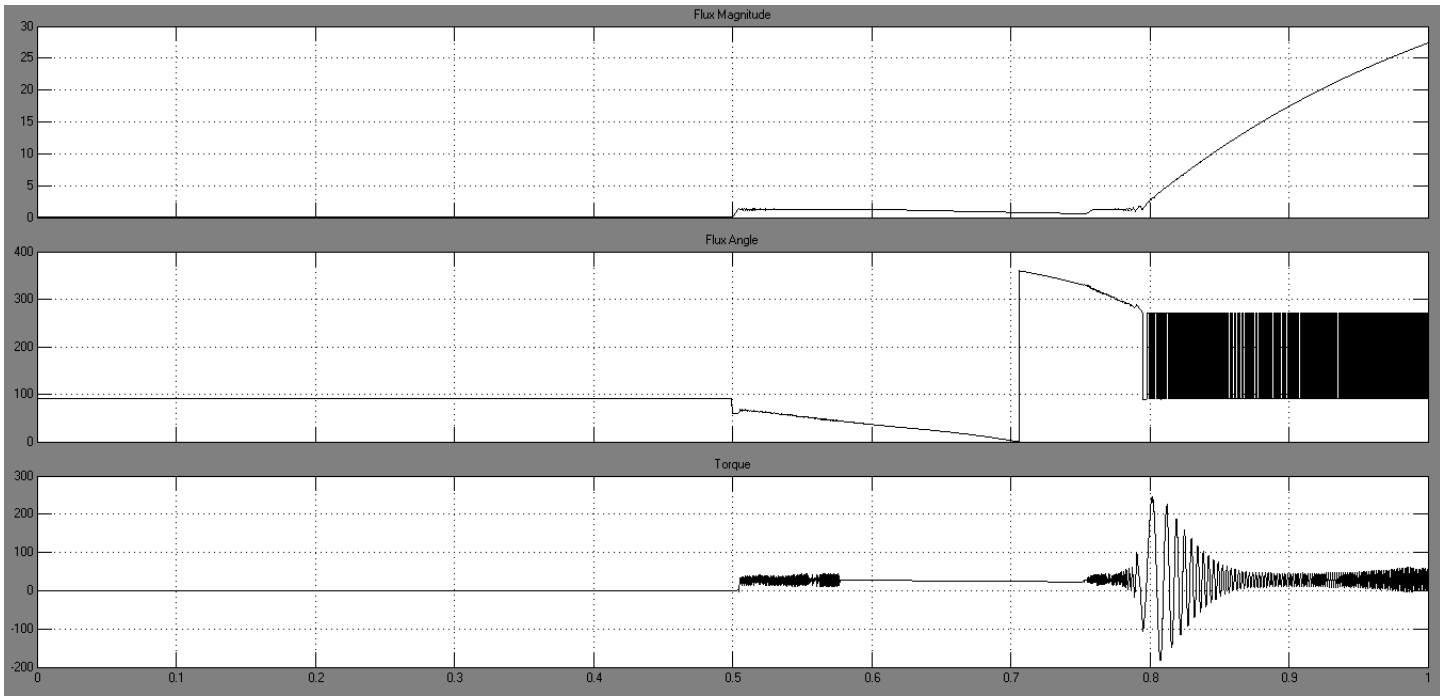
```
      T1=1;
      T3=1;
      T5=1;
    end
  %-------------------------------------------------------------------------%

    if(Hf==0&&Ht==-1&&S==1)
        T1=0;
        T3=0;
        T5=1;
    end
    if(Hf==0&&Ht==-1&&S==2)
      T1=1;
      T3=0;
      T5=1;
    end
    if(Hf==0&&Ht==-1&&S==3)
      T1=1;
      T3=0;
      T5=0;
    end
    if(Hf==0&&Ht==-1&&S==4)
      T1=1;
      T3=1;
      T5=0;
    end
    if(Hf==0&&Ht==-1&&S==5)
      T1=0;
      T3=1;
      T5=0;
    end
    if(Hf==0&&Ht==-1&&S==6)
      T1=0;
      T3=1;
      T5=1;
    end
end
```

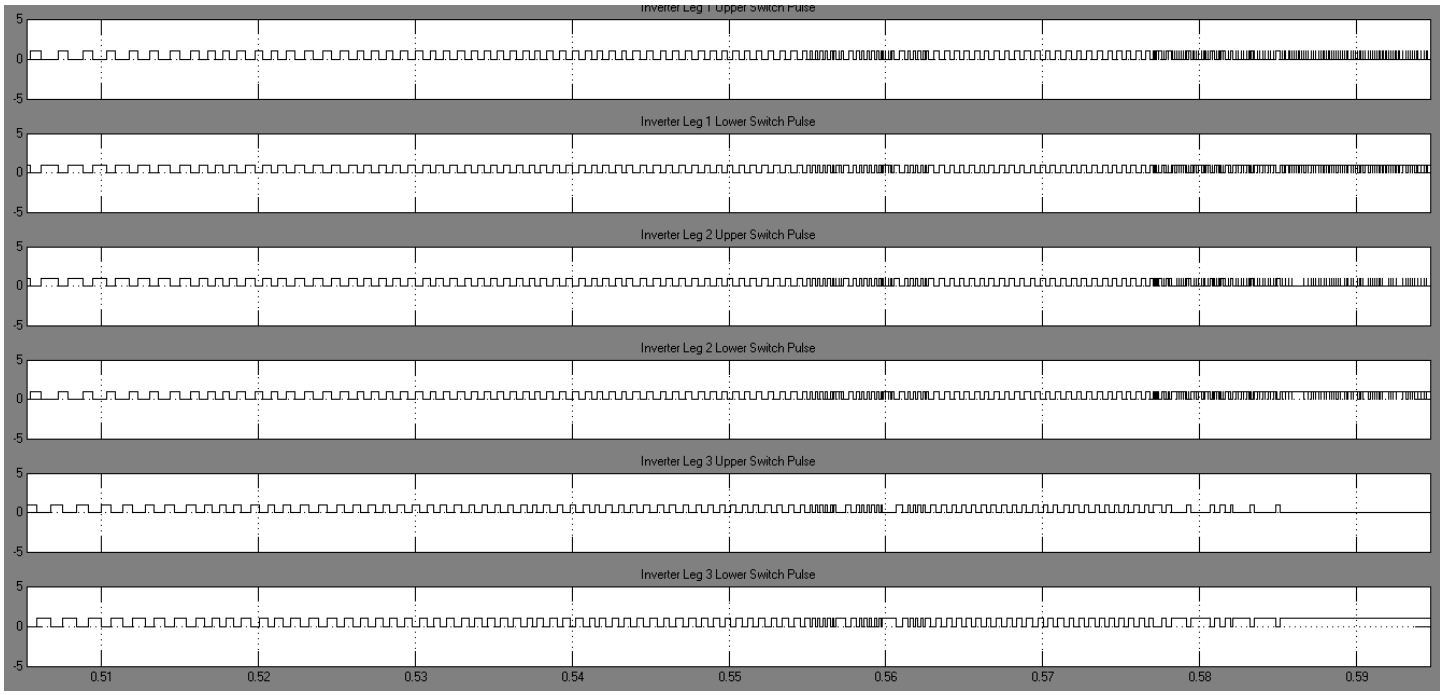
Output:


Stator Phase A Current
50
0
-50
-100
-150
-200
-250
Speed
20
10
0
-10
-20
-30
-40
-50
Torque
300
200
100
0
-100
-200
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Stator d axis Flux
10
0
-10
-20
-30
Stator q axis Flux
2
1
0
-1
-2
Id
-100
-150
-200
Iq
100
50
0
-50
Te
400
200
0
-200
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Vd
400
200
0
-200
-400
Vq
400
200
0
-200
-400
Id
100
0
-100
-200
-300
Iq
100
50
0
-50
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1


Flux Magnitude
30
25
20
15
10
5
0
Flux Angle
400
300
200
100
0
Torque
300
200
100
0
-100
-200
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Inverter Leg 1 Upper Switch Pulse
Inverter Leg 1 Lower Switch Pulse
Inverter Leg 2 Upper Switch Pulse
Inverter Leg 2 Lower Switch Pulse
Inverter Leg 3 Upper Switch Pulse
Inverter Leg 3 Lower Switch Pulse
5
0
-5
0.51
0.52
0.53
0.54
0.55
0.56
0.57
0.58
0.59