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Dynamic Performance of Permanent Magnet Synchronous Machines and Brushless DC Motor Fed Single Phase Source with Different Starting Circuits in Closed Loop Using Simulink

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***Abstract*— This research presents the dynamic performance of the permanent magnet synchronous machines (PMSM) and brushless DC motor (BDCM) fed single phase source with usually starting capacitance circuit and with electronic triac circuit in closed – loop control and compare these process with the dynamic performance of the (PMSM) and (BDCM) motors with three phase source that are been done. These simulation using simulink with needed adaptation and results lead the machines can be used in modern domestics applications that demand only single phase source and small power. The dynamic performance of PMSM and BDCM motors fed single phase source in closed–loop with electronic starter closes to the dynamic start of these motors with three phase source**

***Index Terms*— Electronic circuit with triac, simulink model, PMSM,BDCM**

I. INTRODUCTION

AC permanent magnet (PM) motors work as synchronous and brushless DC motors, 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 [1] (see Fig. 1). The rotor has a permanent magnet.

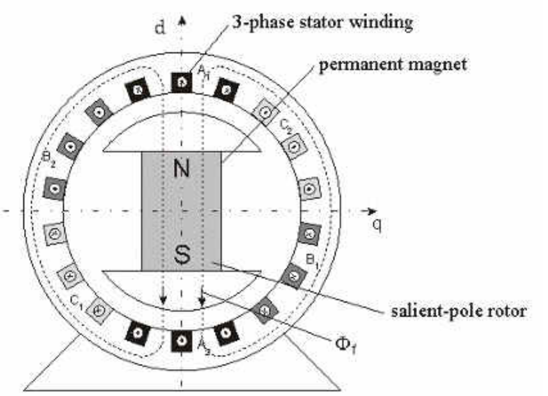

Fig.1.Scheam of three phase PM , salient – pole motor with buried magnet in the rotor

There are two types of rotors: salient-pole rotor (Fig. 1) that is mostly for low-speed machines, and cylindrical rotor (Fig. 2) that is usually used for high-speed machines.

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Since there is no winding in the rotor (that would be supplied through the brushes), 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 stator winding. The AC PM motor when operating in each of the above modes, i.e. synchronous or brushless DC motor, performs differently. Thus, its electromechanical characteristics will differ significantly. Especially when these modes of PM motor fed single phase source instead of three phase source. The BLDC motors are available in many different power rating from very small motors as used in hard disk drives to large motor used in electrical vehicles. Three phase motors are most common but two phase motors are also available in many applications. In the reference [2], the simulation of dynamic state of BLCD motor was presented and the result shown that the torque ripples in three phase system is less when compared to that of two-phase system. The software package MATLAB/SIMULINK was used in many work [3,4]. Dynamic performance of three phase PMSM motors was demonstrated in open and closed loops [5,6,7,8,9]. The references are not up to date because the subject is old.

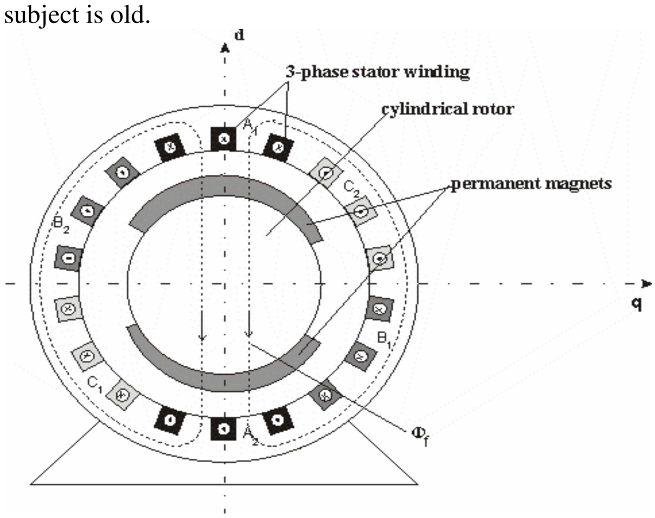


Fig.2. Scheme of three phase PM , cylindrical rotor

This research will use the dynamic circuit demonstrated in the demo of MATLAB/SIMULINK[10] in closed loop control of three phase PMSM and BLDC motors fed by three phase source, moreover, developing the operation and starting these circuits for single phase source using different starting methods. One of these circuits contains a capacitor and the second circuit includes an electronic tricac-starter. Finally, these modified circuits will be compared with the existing PMSM and BLDC motors under operation modes. Moreover, the performance of the permanent magnet motor operating as a brushless DC motor and a synchronous machine shall be investigated.

II. PMSM MOTOR OPERATIONS

The operation modes of PMSM and BDCM motors depend on the supply and control circuits. Fig. 3 shows the stator of these motors with conventional windings placed in slots and distributed symmetrically around the stator periphery. When operating in synchronous or in brushless DC motors, the AC PM motor performs differently, thus significantly. With comparison to [1,2,3,4,5], the object of this research is to determine these differences for each particular operation mode).

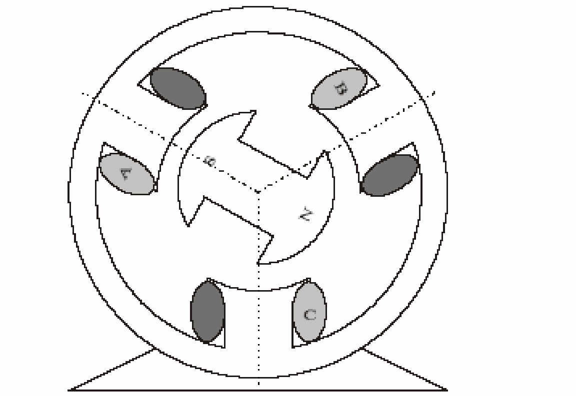


Fig.3.Motor with three-phase constructed winding

2.1 Permanent magnet synchronous motor operation

The 3-phase armature winding of the synchronous motor is connected to a 3-phase AC supply. The stator current produces a rotating magnetic flux, as in 3-phase induction machines, the magnetic flux of the PM's is steady with respect to the rotor. To produce torque, these two magnetic fluxes cannot move with respect to one another. This means that the rotor should rotate with the same speed as the rotating flux produced by the stator. The rotor follows the stator rotating field by an angle $-\delta$. The motor being supplied with rated frequency does not develop any torque at zero speed. For the motor to operate, the rotor should first reach a synchronous speed. This can be done in three ways: (i) by driving the rotor to the synchronous speed (with an external machine), (ii) by starting the rotor (which has to be equipped with a starting cage) as in induction motors, or (iii) by supplying the stator winding with variable frequency, beginning from zero to the rated frequency. The latter method can be used if the winding is supplied from a frequency converter. As a result, the equivalent circuit for the dynamic model of the synchronous motor can be represented by two systems; namely the ABC system, which involves three phases and the system which involves two phases. Models of PMSM are the sinusoidal model assumes that the flux established by the permanent magnet in the stator is sinusoidal, which implies that the electromotive forces are sinusoidal and the trapezoidal model that assumes the winding distribution and flux established by the permanent magnets produce three trapezoidal back EMF waveforms. Schematic circuit shown in Fig.4 illustrates the use of the trapezoidal model of PMSM fed three phase source in closed–loop speed and current control of motor as in the reference[10]. In this circuit, a three phase motor rated 1.1 KW, 220v, 3000rpm is fed by a pwm inverter [10]. Two control loops are used; the inner loop regulates the motor's stator currents, while the outer loop controls the motor's speed. The equations describes the dynamic trapezoidal model of PMSM are expressed in the phase references frame (abc frame) are not used in the model but is used standard Simulink blocks. Note that the phase inductance Ls is assumed a constant and does not vary with rotor position.

$$\frac{d}{dt}i_a = \frac{1}{3L_s}[2v_{ab} + v_{bc} - 3R_s i_a + \lambda p\omega_r(-2\phi_a' + \phi_b' + \phi_c')] \quad (1)$$

$$\frac{d}{dt}i_b = \frac{1}{3L_s}[-v_{ab} + v_{bc} - 3R_s i_b + \lambda p\omega_r(\phi_a' - 2\phi_b' + \phi_c')] \quad (2)$$

$$\frac{d}{dt}i_b = -\left(\frac{d}{dt}i_a + \frac{d}{dt}i_b\right) \quad (3)$$

$$T_e = p\lambda(\phi_a' . i_a + \phi_b' . i_b + \phi_c' . i_c) \quad (4)$$

$$\frac{d}{dt}\omega_r = \frac{1}{J}(T_e - F\omega_r - T_m) \quad (5)$$

$$\frac{d\theta}{dt} = \omega_r \quad 6)$$

Where the electromotive force Φ is represented by trapezoidal waves versus θ electric and Ls-Inductance of the stator winding; R-Resistance of the stator windings ; ia,ib, ic-a,b and c phase currents; Φa′, Φb′, Φc′-a,b and c phase electromotive forces; Vab ,Vbc –ab and bc phase to phase voltages; ωr-angular velocity of the rotor; λ-amplitude of the flux induced by the permanent magnets of the rotor in the stator phases, P-number of pole pairs; Te-electromagnetic torque; J-combined inertia of rotor and load; F- combined viscous friction of rotor and load; θ- rotor angular position; Tm-shaft mechanical torque.

2.2 Brushless DC (BLDC) Motor operation

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. The BLDC motor model is shown in Fig.5. Another assumption is that there are no power losses in the inverter and the 3-phase motor winding is connected in star. The BLDC motor has to be equipped with a position sensor which informs the controller what the position of the rotor magnetic pole, with respect to the particular stator phase winding. This is done in order to switch the motor ON and OFF.The position sensors that are applied are usually optical and Hall's. In the experiments that shall be carried out in this project, the encoder is expected to work as a position sensor. The BLDC motor can also operate by using sensor-less control. In this case, the position of the rotor is known from the value of the back EMF with respect to the particular phase.

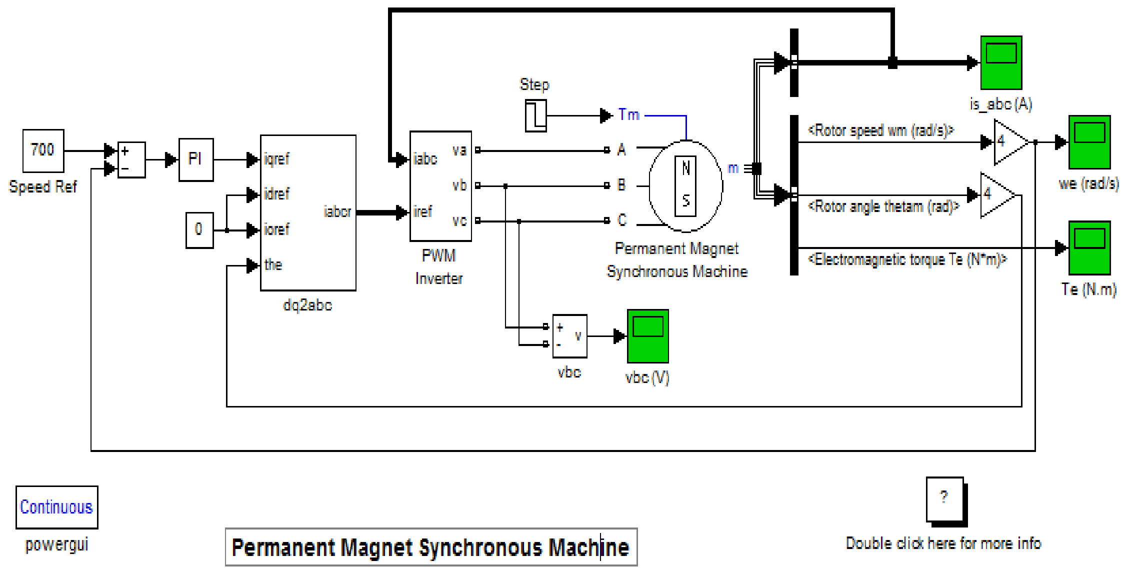


Fig.4.Permanent magnet synchronous machine model

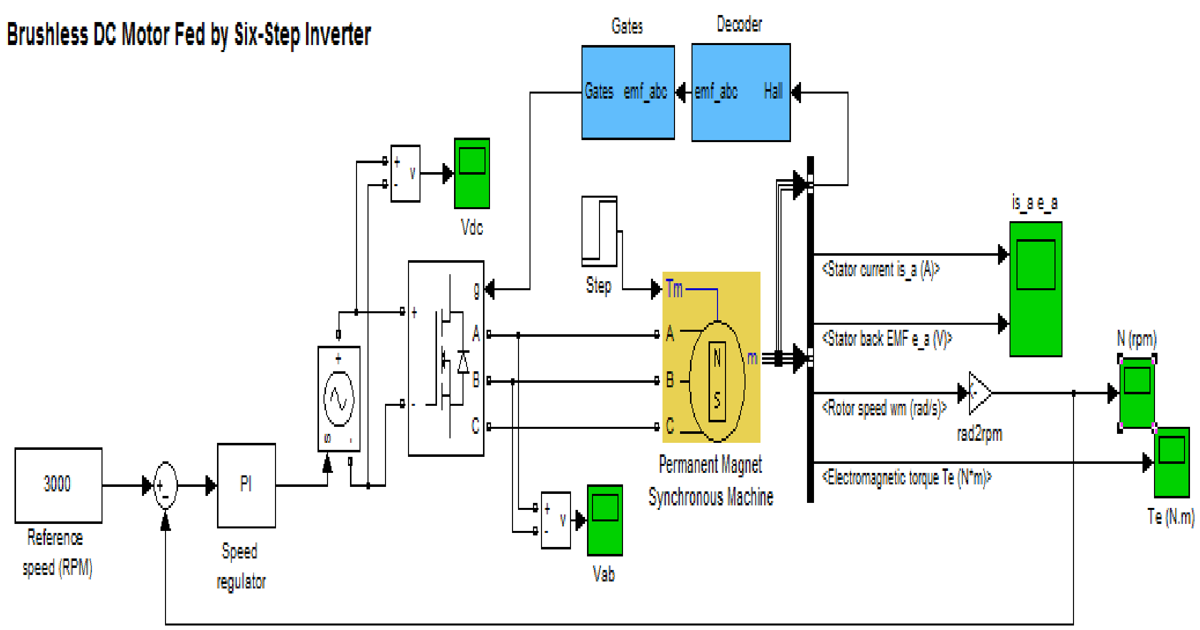


Fig.5.Dynamic model of BLDC motor

3. SIMULATIONS OF MOTOR DYNAMICS AND RESULTS

3.1 Permanent synchronous motor

The simulation of the PMSM motor fed three phase source in a closed – loop speed and current control was done using MATLAB/SIMULINK. For this purpose the motor's block diagram shown in Fig.4. [10]. Circuit contains a three- phase motor rated 1.1KW, 220V, 3000 rpm that fed by a PWM inverter. The PWM inverter is built entirely with standard simulink blocks. The load torque applied to the machines' shaft is originally set to its nominal value(3N.m) and steps down to 1N.m at t = 0.04 s. Two control loops are used [10]. The inner current control loop and the outer control speed loop.

The simulation of the PMSM motor feed single phase source is constructed as shown in Fig.6. The capacitor starting circuit is connected between phase b and c of PMSM motor.

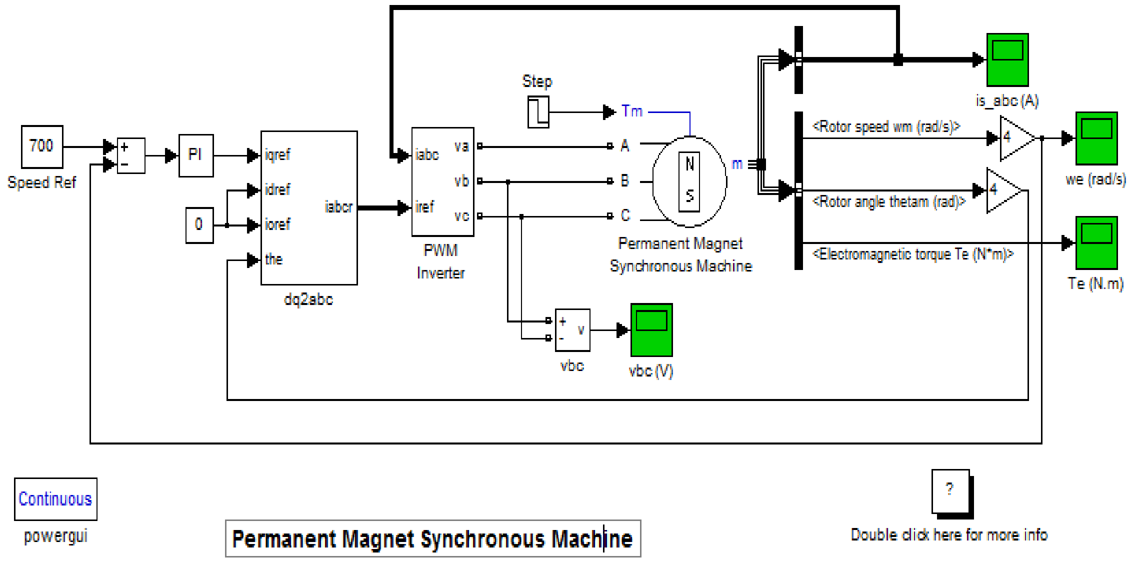


Fig.4. Block Diagram for PMSM motor feed three phase source in a closed- loop speed and current control

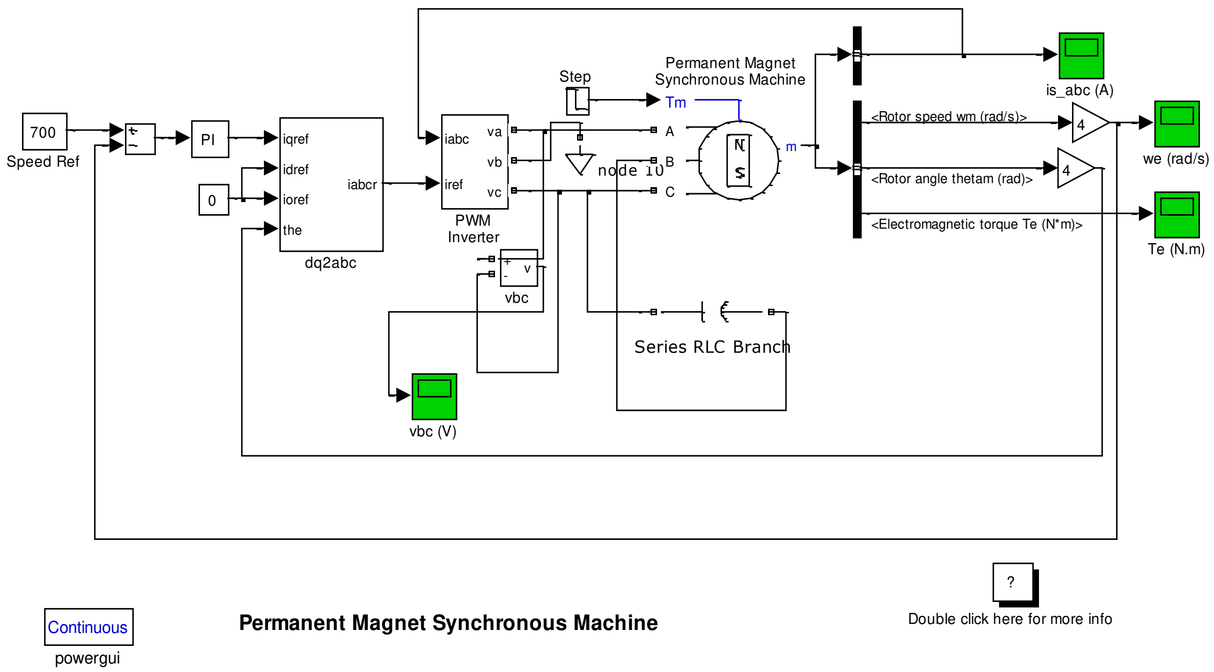


Fig.6. Block Diagram for PSMS motor in closed loop and operation with capacitor starting circuit.

The electronic starting circuit is constructed with two thyristors (triac) with firing circuits as shown in Fig.7. Firing circuit of thyristor generate signal with delay angle equal 90° and the second firing circuit generate signal with delay angle equal 90°plus π. This electronic circuit is connected with phase b and phase c of PMSM motor as shown in Fig.7. The block parameters of PMSM motors were shown in Fig.8.

After running the simulation for each system shown in Fig.4; Fig.6 and Fig.7, the speeds and torques waveforms were recorded and analyzed.

Fig.9 shows the start-up process of the motor with different starting circuits. Fig.9(a) shows the electromagnetic torque waveform Te with noise that is introduced by the PWM inverter. This noise is not appearing in the motor's speed waveform (motor's inertia prevent it). Fig.9 (b) shows the noise in the electromagnetic torque and in the speed waves is clearly observed especially in electromagnetic torque wave. While the noise in the electromagnetic torque and in the speed waves of Fig.9 (c) is observed the same as in the waves of fig.9 (a).

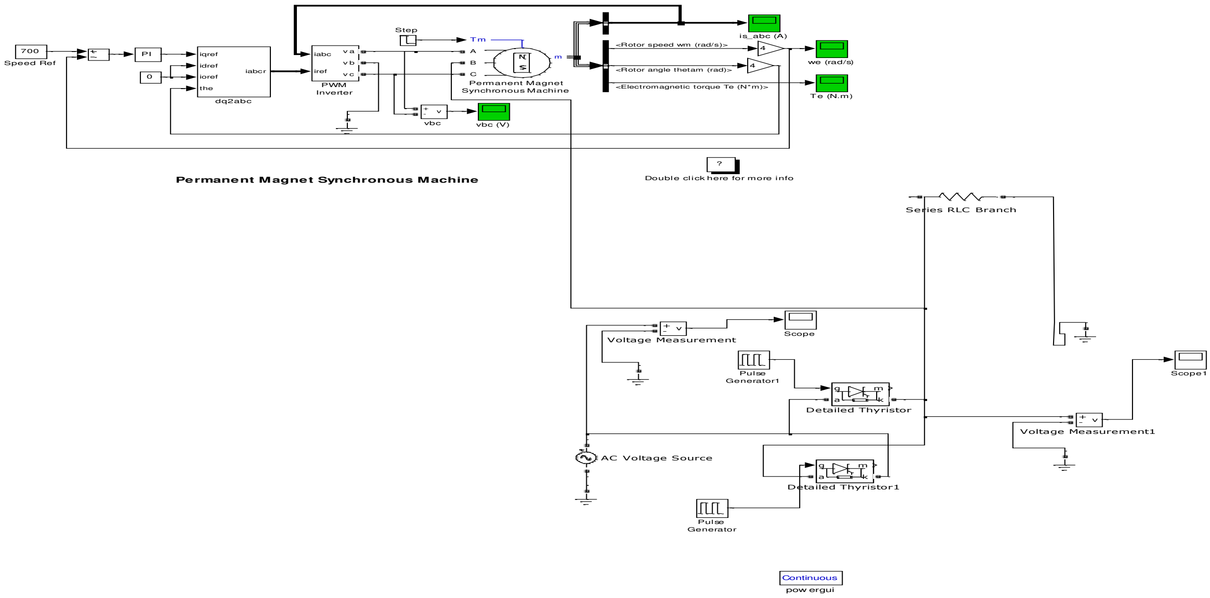


Fig.7.Bock diagram for PMSM motor in closed loop control and operation with electronic starting circuit.

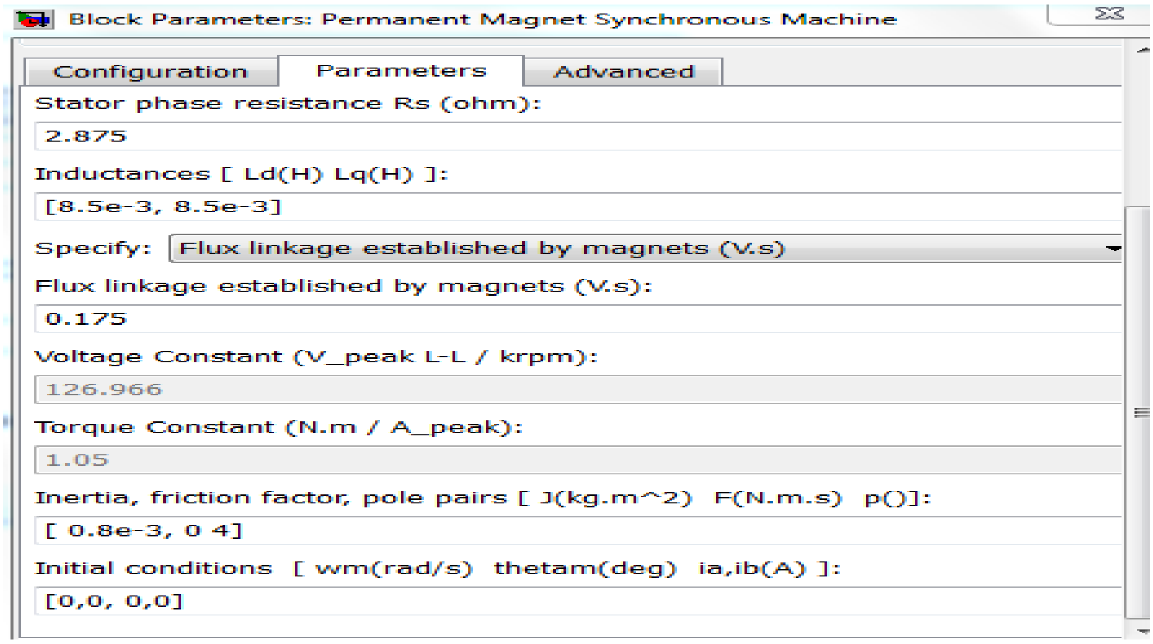
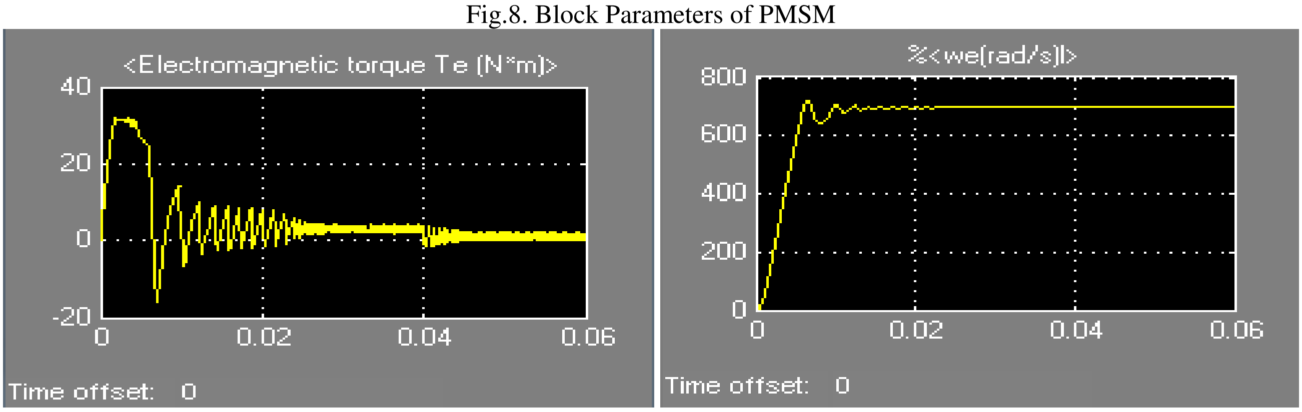
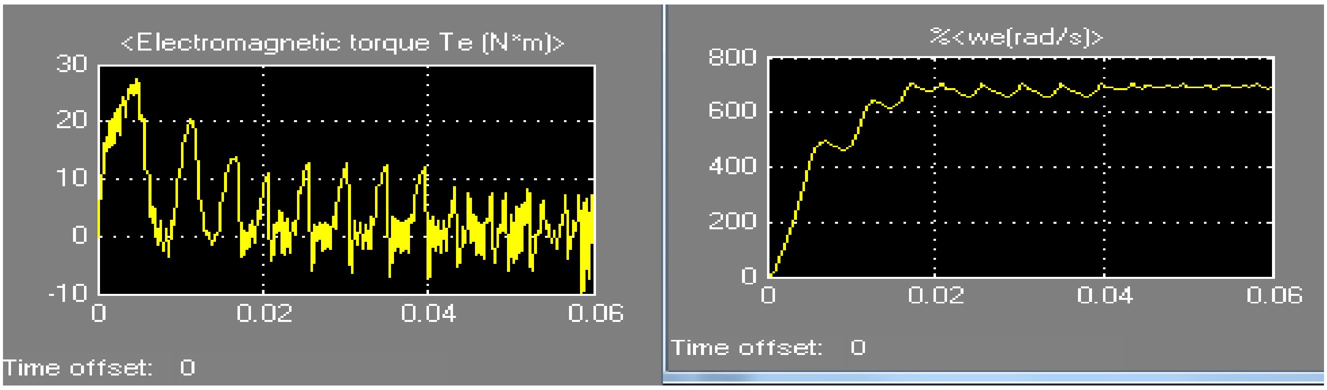


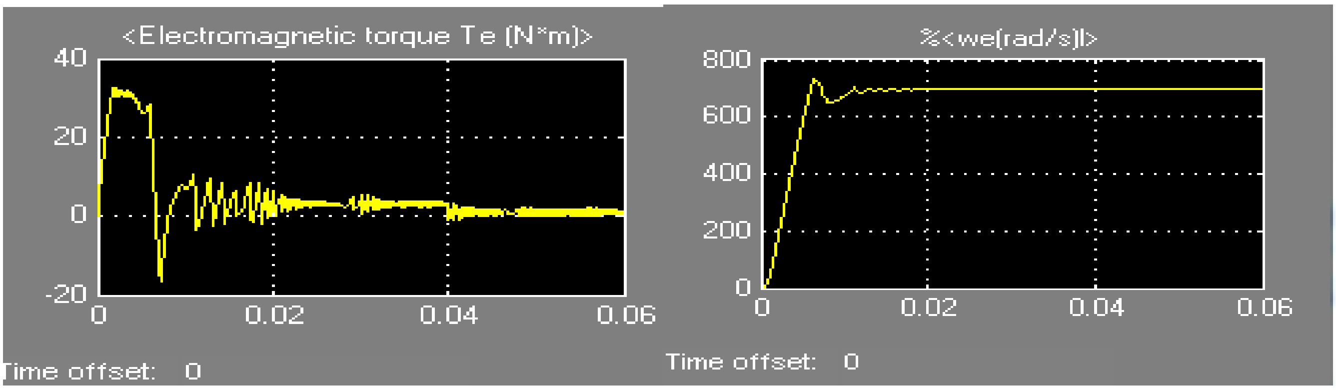
Fig.8. Block Parameters of PMSM



A



B



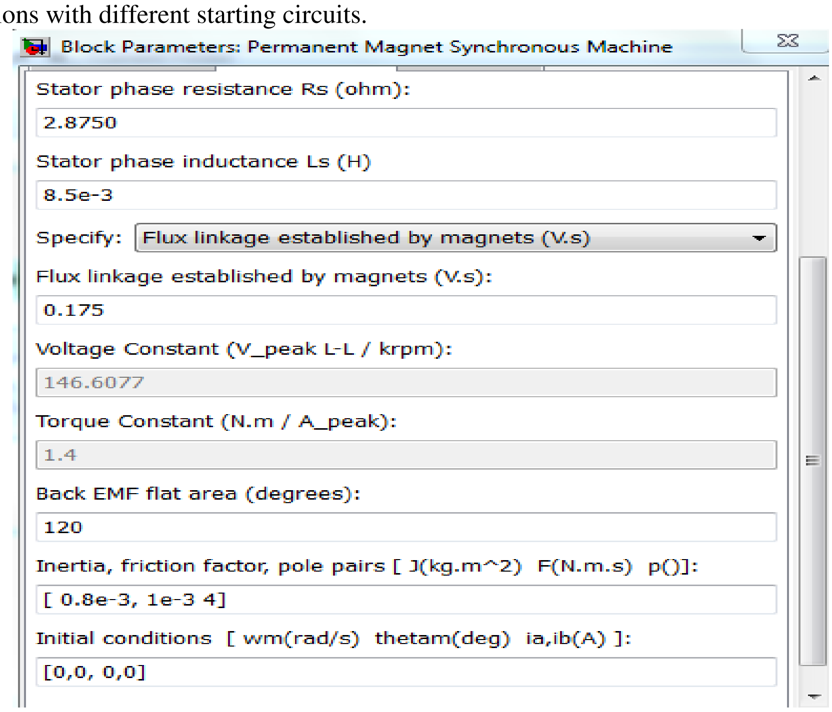
C

Fig.9 Waveforms of mechanical quantities obtained from:

A. The start –up process of the PMSM motor with three phase source.
B. The start – up process of the PMSM motor fed single phase source with capacitor.
C. The start – up process of the PMSM motor fed single phase source with electronic stating circuit.

3.2 Brushless DC motor

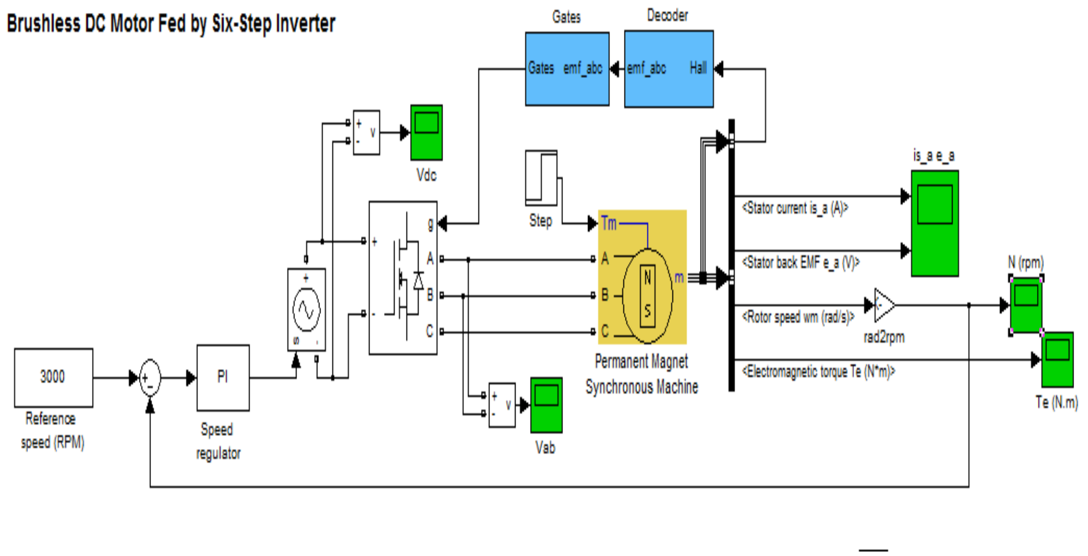
The circuit that used the permanent magnet synchronous machine in motoring mode with a closed-loop control system shown in Fig.5 [10]. The system includes a six step inverter block from the SimPower System Library. Two control loops are used; the inner loop synchronizes the pulses of the bridge with electromotive forces; and the outer loop regulates the motor's speed, by varying the DC bus voltage. The mechanical torque applied at the motor's shaft is originally 0 N.m (no load) and steps to its nominal value (3 N .m) at t is 0.1 second. The parameters of the machine are shown in fig.10.[10]. Fig.11 shows blocks diagram of BLDC motor operations with different starting circuits.


Block Parameters: Permanent Magnet Synchronous Machine

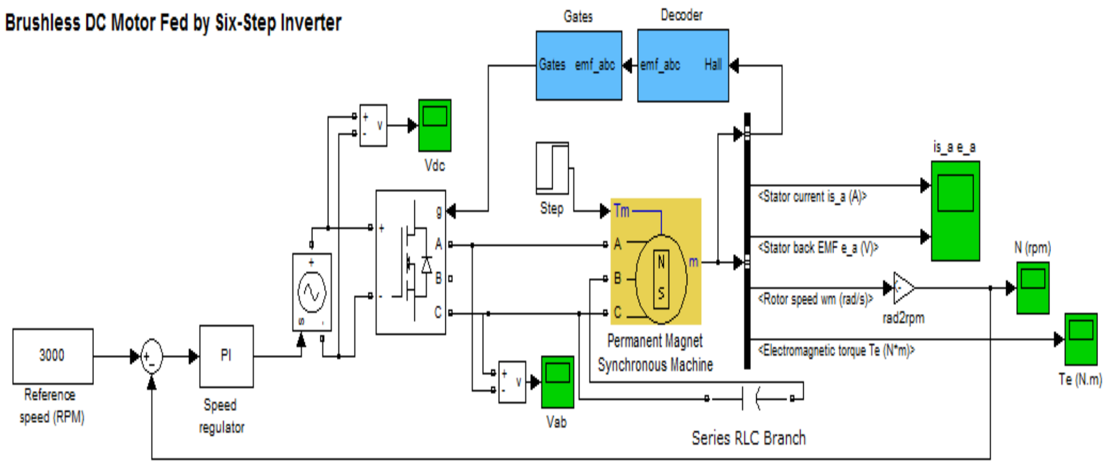
Stator phase resistance Rs (ohm):
2.8750
Stator phase inductance Ls (H)
8.5e-3
Specify: Flux linkage established by magnets (V.s)
Flux linkage established by magnets (V.s):
0.175
Voltage Constant (V_peak L-L / krpm):
146.6077
Torque Constant (N.m / A_peak):
1.4
Back EMF flat area (degrees):
120
Inertia, friction factor, pole pairs [J(kg.m^2) F(N.m.s) p()]:
[0.8e-3, 1e-3 4]
Initial conditions [wm(rad/s) thetam(deg) ia,ib(A)]:
[0,0, 0,0]

Fig.10. Parameters of the machine

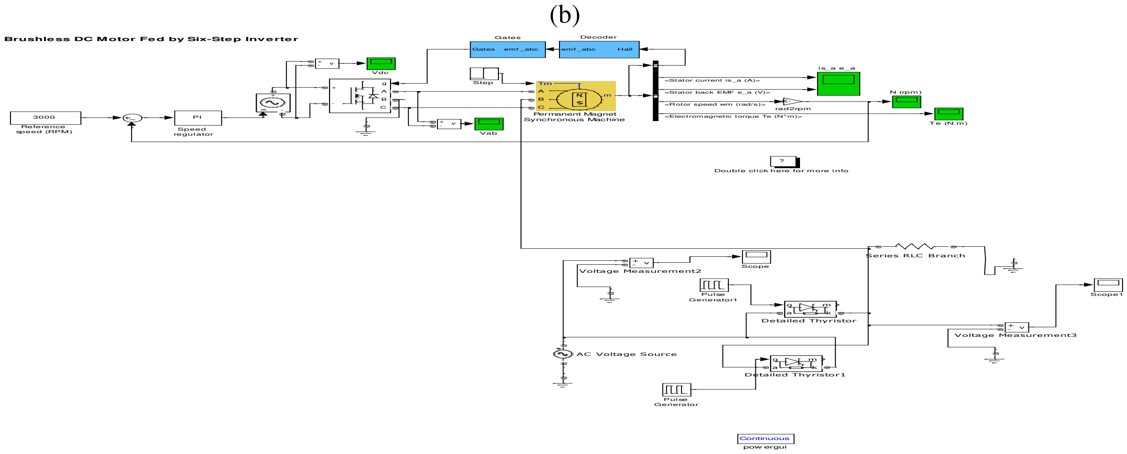
After running the simulations, the speeds and torques waveforms were recorded and analyzed. Fig.12 shows the start-up process of the motor. The torque climbs to nearly 28 N.m when the motor starts(Fig.12.(a) and stabilizes rapidly when the motor reaches the reference value. The nominal torque is applied at t = 0.1 second and the controller reacts rapidly and increase the DC bus voltage to produce the required electric torque. As shown in Fig12.(a) the electromotive torque is saw tooth waveform while the noise of motor's speed wave is not appearing as the motor's inertia is exist. The increasing noises (oscillating) of motor's speed wave and electromotive torque are observed when the motor starts with single phase source with starting capacitor as shown in fig.12(b). The stating – up with fed single phase source with electronic starting circuit (Fig.12(c))the motor's speed wave and the motor's electromotive torque wave show the noise may be is closely with accepted increasing to the start-up process of the motor shown in the Fig.12(a).



(a)



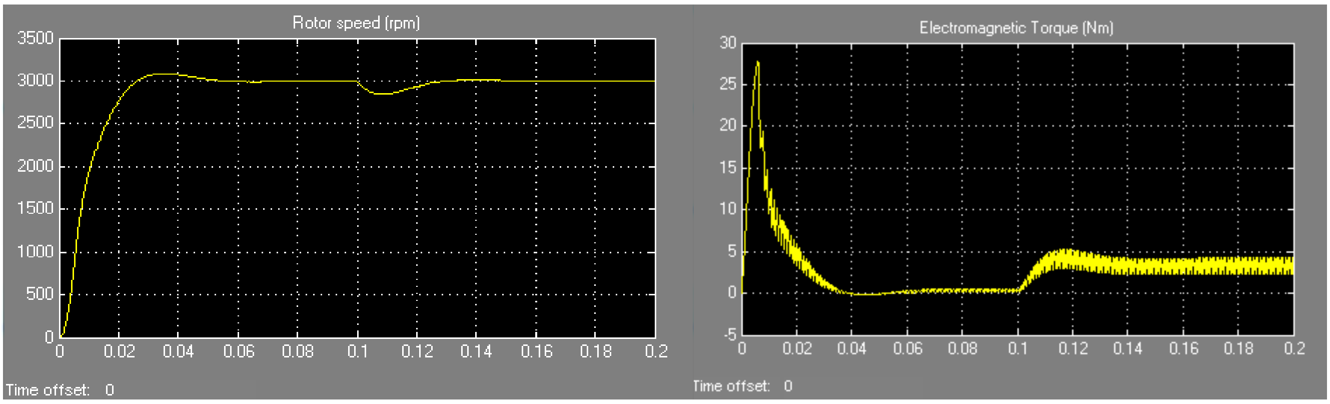
(b)



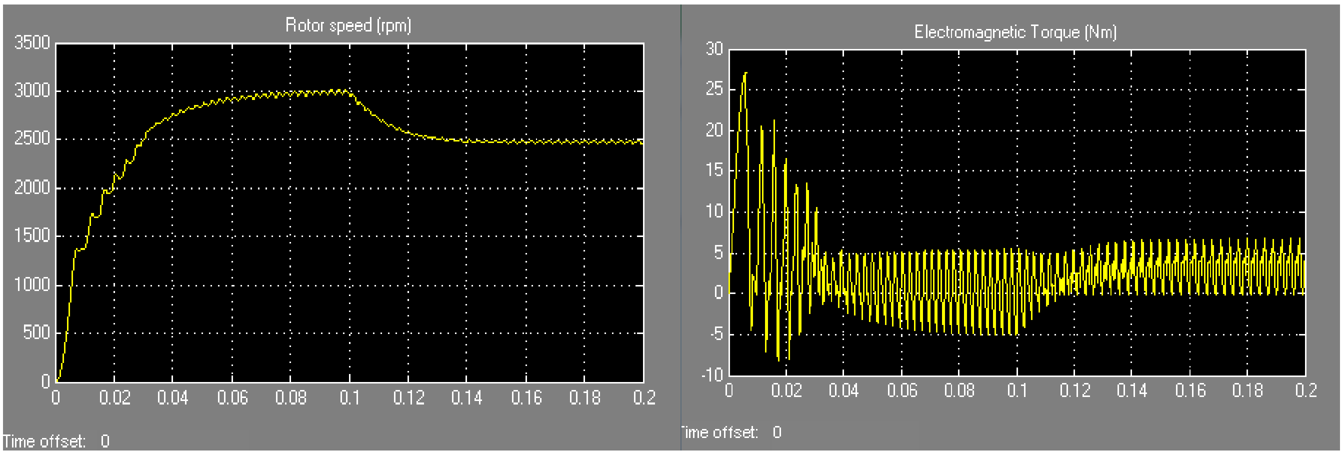
(c)

Fig.11. Blocks Diagrams for BLDC motor operation:

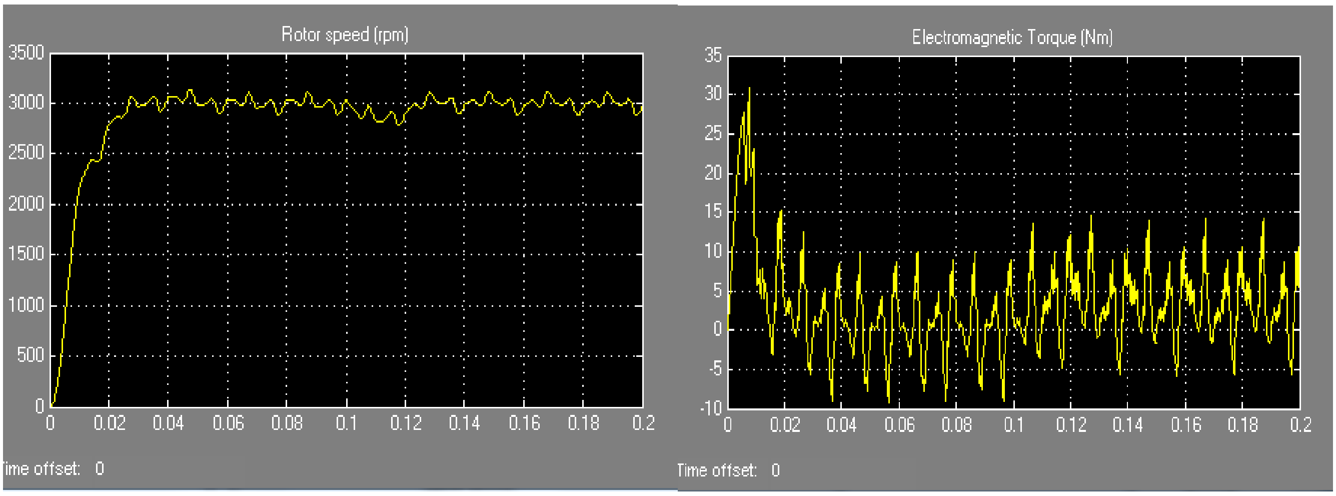
A. Fed three phase source
B. Fed single phase source with capacitor starting circuit
C. Fed single phase source with electronic starting circuit



(a)



(b)



(c)

Fig.12 Waveforms of mechanical quantities obtained from:
A. The start –up process of the BLDC motor with three phase source.
B. The start – up process of the BLDC motor fed single phase source with capacitor.
C. The start – up process of the BLDC motor fed single phase source with electronic stating circuit

Conclusion

The performance of a 3-phase permanent magnet motor operating as a synchronous and BLDC motor fed three phase source and fed single phase source with capacitor starting circuit and with electronic starting circuit were analyzed in this research as maintained in the proposal research project. The software package MATLAB/SIMULINK was used to design the block diagrams with electronic stating circuit and with starting capacitor circuit and run the simulations. The results were then compared with those gotten in MATLAB/SIMULINK for the three phase source data. The noise with increasing pulsating noise introduced by the capacitor staring circuit is observed in the electromagnetic torque and speed waves, while the operating this motor with electronic starting circuit showed the matching of dynamic performance for the motor with three phase source.

The BLDC motor, which operated with capacitor starting circuit, showed the difference especially in the speed wave, when is applied the mechanical torque. The speed drops down less the set point in addition to the increasing of the oscillating that is observed in torque and speed waves. The BLDC motor, which operated with electronic starting circuit, showed the synchronous motor which operated with capacitor starting circuit, showed the the noise is in electromagnetic torque and speed waves. The dynamic process in this case has the increasing amplitude, while the others dynamic parameters are near were compared.

The research result shows, the using of motor with electronic starting circuit as synchronous permanent motor or as BLDC in closed loop control systems with single phase source can be in domestic or industry sectors

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