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Modeling and Simulation of Pulp Mill Permanent Magnet Synchronous Machines with Damper Windings Using Matlab/Simulink

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Abstract

Modeling and simulation of pulp mill plant permanent magnet synchronous machines (PMSM) with damper windings using Matlab/Simulink is presented. Pulp mill is a manufacturing facility that converts wood chips, timber, wood products into wood pulp that is used to produce paper, cardboard, thick fiber board, which can be used by a paper mill for further processing. Pulp and paper industry has been considered a large consumer of energy and constitute a native treat to the plant as a result of machines transient due to heavy load variation. Modeling and simulation of pulp mill plant (PMSM) with damper windings show the behavior of machines virtual image environments to test the performance, stability and safety for less cost. It helps the pulp mill plant designers, engineers and technicians to understand the process of creating and analyzing machines model and predict its performance in the real world. Damper winding is an additional property added in pulp mill plant PMSM to damping out any oscillation that may cause any sudden changes in the load on the rotor when in synchronism. It prevents hunting and provides starting torque and dose not requires machines spinning. The rotor field lags the stator by which the load angle changes as a result of load variation. Permanent magnet synchronous machine (PMSM) is an alternating current (ac) machine whose excitation is provided by the permanent magnet. It has permanent magnet (PM) on the rotor and windings on the stator. PMSM does not have field windings on the stator frame instead, it relies on the magnets to provide the magnetic field against which the rotor interacts to produce a torque. Pulp mill plant PMSM with damper windings was modeling and simulated using Matlab/Simulink as presented in this paper. The electrical and mechanical equations of various steps ware developed in state space form from which the SIMULINK models were built with pulp mill plant PMSM with damper windings using the block-approach method with in-built Matlab/SIMULINK to obtained results for dynamics performance, controllability, stability study and is widely used in the engineering, manufacturing, physical sciences, product development and recommended for pulp mill plant designers, engineers, technicians and plant operators.

Keywords: Pulp-mill, Fiber, Damper, Oscillation, Synchronism, Spinning, Reluctance, Commutation.

INTRODUCTION

Modeling and simulation of pulp mill plant permanent magnet synchronous machine (PMSM) with damper windings using Matlab/Simulink is presented. Pulp mill is a manufacturing facility that converts wood chips, timber, wood products into wood pulp that is then used to produce paper**,** cardboard, thick fiber board, which can be used by a paper mill for further processing. The pulp and paper industry has been considered a large consumer of wood, energy and water, Pulp is used in a variety of consumer and special products, such as: paper, printouts, receipts, poster and envelopes. Paper cups, napkins, toilet rolls, tissues, cardboard, diapers and baby wipes, LCD screens, shoes, handbags and food casings and this constitute a native treat to the plant as a result of heavy machines transient and load variation.

Modeling and simulation of pulp mill plant PMSM with damper windings show the behavior of machines that use virtual image environments to test the performance, stability and safety for less cost. Simulation modeling help the pulp mill plant designers, engineers and technicians to understand the process of creating and analyzing a digital prototype of a machines model and predict its performance in the real world and is widely used in the engineering, manufacturing, physical sciences, and product development to evaluate a new design, diagnose problems with an existing design, and test a system under conditions that are hard to reproduce in an actual system.

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SIGNIFICANT OF PULP MILL PLANT PMSM MODELING AND SIMULATION

The modeling and simulation improve the quality of the pulp mill plant system design, thereby reducing the number of errors in the design process. In the early phase of the design process, where the hardware are not readily available, modeling and simulation play a very important role for test conditions that might be difficult to reproduce with hardware. The time and cost for development is significantly reduced. In this paper MATLAB/Simulink are tools used for modeling and simulation include block diagrams.

The increasing demand and popularity of permanent magnet synchronous machines (PMSM) with damper windings for industrial applications has called for greater attention in electrical machines industry because of machines special characteristics torque and control [1, 11, 12]. The speed and torque characteristics can be varied over a wide range of applications while the PMSM with damper windings maintains its efficiency without sacrificing its dynamic performance as comparers to other conventional machines [3, 5, 6]. In pulp mill plant PMSM have always been used where good controllability, efficiency and dynamic performance is highly demanded. [2, 7, 9, 11]

Modeling and simulation of pulp mill PMSM with damper windings using Matlab/Simulink as presented in this paper, the electrical and mechanical equations of various steps ware developed in state space form from which the SIMULINK models were built.

DAMPER WINDING

Damper winding is an additional property added in pulp mill plant PMSM that damping out any oscillation that may cause any sudden changes in the load on the rotor when in synchronism. Damper winding in PMSM prevents hunting and provides starting torque and dose not requires machines spinning. The rotor field lags the stator by which the load angle changes as a result of load variation.

Permanent magnet synchronous machine (PMSM) is an alternating current (ac) machine whose excitation is provided by the permanent magnet. It has permanent magnet (PM) on the rotor and windings on the stator. PMSM is a rotating electric machine where the stator is classic, the three phase stator like that of induction machines and the rotor has permanent magnets. A PMSM does not have field windings on the stator frame instead; it relies on the magnets to provide the magnetic field against which the rotor interacts to produce a torque. Compensating windings in series with the armature may be used on large motors to improve commutation under load. Because of PM involve in PMSM, they cannot maintain a high flux if disassembled.

The additional windings on the rotor are known as DAMPER WINDINGS whose function is to damped out any oscillation that might cause sudden change in the load on the rotor when in synchronism. Electrical machines have advanced significantly in the recent years due to the introduction of new materials. This has reduced losses and rare – earth PM materials that provide a “losses” source of magnetic flux. [1, 5]. Simulate of the characteristic of electrical machines system PMSM with and without damper windings to ensure high stability of output voltage and frequency for electrical power network without the external technical starting equipment was investigate in the laboratory base on the machine parameters see figure1.

The mathematical modeling and performance analysis of a PMSM was obtained by fitting a permanent magnet inside the cage rotor of machine [2, 6]. The magnets in these machines are frequently buried in the rotor to provide space for the rotor cage close to the surface of the rotor [4, 7]. Who Points out that the presence of the magnet provides a reluctance torque that is opposite in sign to that of a wound rotor synchronous machine. Reviews of the development of PMSM and consider the effects of variations of parameters on its performance. Whereas. [8, 10, 12] Looks at the characteristics of several of magnet and views the possibilities for use in permanent magnet motors. An analysis of a PMSM with a cage rotor operation of a fixed 60 Hz supply was done in [9].

A detailed steady state analysis was done [10,11] while the starting performance has been studied [11, 13, 14] using the d, q axis equation of a PMSM with damper windings and the rotor cage contributing to the iron saturation, due to the rotor induced currents. Parameter sensitivity of self-starting of PMSM was considered in [4, 5, 9] while the measurement of motor parameters was examined in [1, 9] PMSM performance has been considered both after [7, 8] and before synchronization. In [6, 8], the effects of iron losses are included in the model. The effects of the magnet and cage torques on the ability of the machine to run up on load are examined in detail and the sub synchronous torque is divided into its constituents. Starting performance and steady state operation for a single phase PMSM was dealt with [1, 9].

STARTING OF PUL MILL PMSM WITHOUT TECHNICAL STARTING EQUIPMENT

Pulp mill PMSM with synchronous damper windings can be started without any additional technical equipment. Damper windings were used to run the machine up to the speed of the induction motor action with the machine pulling into synchronism by the combination of the reluctance and synchronous motor torque provided by the magnet. During the start-up, the magnet exerts a braking torque that opposes induction motor type torque provided by the damper windings. [8, 9]. The torque provided by the damper windings must therefore overcome the magnet braking torque, in addition to the load and friction to run the motor up successfully.

There are two types of machines base on the nature of electromagnetic force (EMF) and current produced. AC machines and dc machines. The ac machines can be further classified as: Synchronous machines and Induction machines. Machines have normally field windings on the rotor and three-phase windings on the stator. The field winding is supplied by a separate dc source. The field winding produces a field and due to rotation of the rotor, the field moves in the space at the speed of the rotor. This rotating links with three- phase stator conductors and hence voltage is induced in them. The magnitudes of voltage depend upon the strength of magnetic field, number of turns and frequency corresponding to poles and r.p.m for an alternator. For asynchronous motor, three-phase supply can be vary with time, so that a rotating field at a synchronous speed is produced in the air gap of the machines. In the rotating field, North and south poles rotates at a synchronous speed and as north and south poles rotates at synchronous speed, the field produced by the rotor conductor react with the stator field.

Initially, the stator poles interact with the rotor poles and since rotor is at standstill and stator poles rotating at asynchronous speed, if the north poles of the stator field is in contact with south poles of the rotor at any instant, the interactive force will be observed by the rotor and it will try to move in the direction of the stator rotating field. But sooner after the south poles of the stator field come in contact with the poles of the rotor and the repulsive force will act upon the rotor. Hence, a pulsation force acts upon a stationary rotor and so it does not move. This is why a three phase synchronous motor is not self-starting. We can rotate the rotor of the motor by some other means at the synchronous speed so that north and south poles of the stator and rotor field (opposite poles) are coupled (magnetically locked) with each other. The motor keeps on rotating at asynchronous speed.

In other to make itself starting, is to provide damper windings on the rotor of the motor. Damper windings on the other hand behave like the cage rotor of the three-phase induction machines. So three-phase synchronous motor with damper windings is started as induction machine without any technical equipment, and pick up the speed nearer to the synchronous speed. Damper windings is a short circuited windings which are useful in preventing the hunting (momentary) speed fluctuation in alternator and are needed in synchronous motor to provide starting torque. Damper winding is a part for circulation of induced currents when the generator is operating at other than rated speed.

D-Q CIRCUIT MODEL EQUIVALENT OF THE PMSM

The structure of the Permanent Magnet Machine (PMSM) with damper windings and the cross sectional layout of the surface mounted PMSM is shown in figure1.

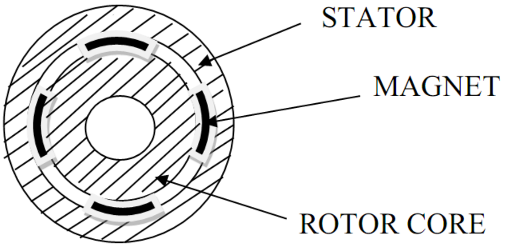

Figure 1: Structure of the permanent magnet synchronous machine [6, 9]

The stator three phase winding, which produces nearly sinusoidal distribution of Magnetomotive force based on the value of the stator current. The magnets are mounted on the surface of the motor core. They have the same role as the field winding in a conventional synchronous machine except their magnetic field is constant and there is no control on it [6, 9].

D-Q model equivalent of PM machine show in figure 3a &3b is similar to the one for the synchronous machine; it has the armature resistance R, d and q axis leakage and mutual inductance ls, Lmd and Lmq. [4,7, 9] The equivalent circuit of the motor is used for the study and simulation of motor. From the d-q modeling of the motor using the stator voltage equation the equivalent circuit motor can be derived. Assuming rotor d axis flux from the PMSM is represented by a constant current source as describe in the following equation $\lambda_q = L_{dm} i_f$ See figure 2.

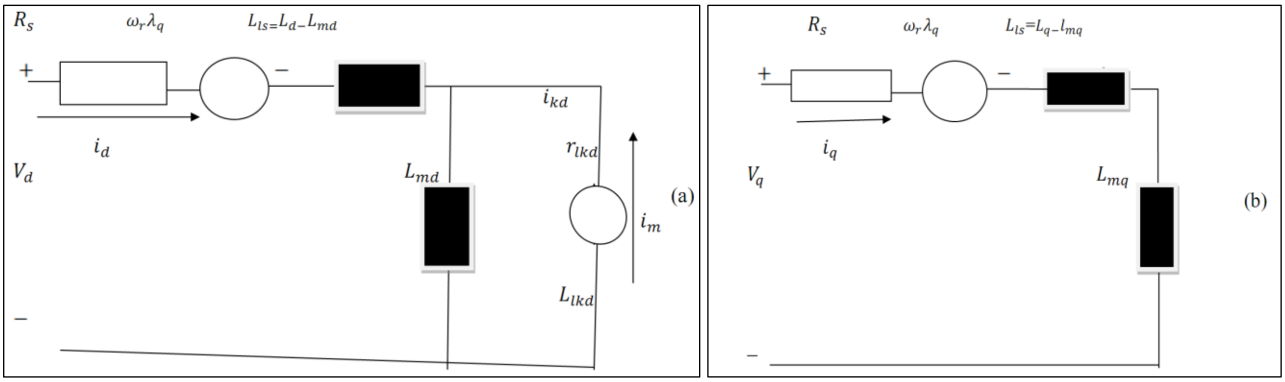

Figure 2: Equivalent circuit of (a) Direct Axis (b) Quadrature Axis of pulp mill permanent magnet synchronous machine with damper windings

The rotor magnet can be considered as a loop of constant current source, im located at the stator direct axis. Any change in the magnetic flux of the rotor magnet will cause an induced electromagnetic force, resulting in a circulating current in the magnet [6, 7, 8]. Essentially resistance Rm connected across the d-axis magnetization inductance Lmd show this effect [4, 5]. There is no leakage inductance in the field. The permeability of the magnet material is almost unity so the air gap inductance seen by the stator is the same in d and q axis and also no saturation will happen inside the machine. This model is similar to the conventional equivalent circuit of the synchronous machine, except there is no leakage inductance on the field [6, 7].

The stator of the PMSM with damper windings and the wound rotor SM are similar. The permanent magnets used in the PMSM are of a rare-earth variety with high resistively, so induced current in the rotor are negligible. In addition there is no difference between the back EMF produced by a permanent magnet and that produced by an excitation coils. Hence the mathematical model of PMSM is similar to that of wound rotor SM. The following assumption are made in the derivation, Saturation current is neglected although it can be taken into account by parameter changes, The induced EMF is sinusoidal, eddy current and hysteresis loss are negligible, there are no field current dynamics, and there is no cage on the rotor.

MATHEMATICAL MODELLING OF PMSM with damper windings

For a balanced pure sinusoidal three phase supply, the sum of the three phases, voltages are zero; as a result, the zero-sequence voltage will be zero. The voltage transformation in the stator reference frame for this type of source can be written as the stator of the PMSM with damper windings as the wound rotor SM are similar [8, 9].

With these assumptions, stator d, q equations of the PMSM in the rotor reference frame are [1, 4].

$$V_q = R\,i_q + p\lambda_q + \omega_s\lambda_d \quad (1)$$

$$V_d = R\,i_d + p\lambda_d + \omega_s\lambda_q \quad (2)$$

Where

$$\lambda_q = L_q\,i_q \quad (3)$$

And

$$\lambda_d = L_d\,i_d + \lambda_{df} \quad (4)$$

V_d and V_q are the d, q, axis voltages, i_d and i_q are the d, q axis stator current, L_d and L_q are the d, q axis inductance, λ_d and λ_q are the d, q axis stator flux linkages. While R and ω_s are the stator resistance and inverter frequency, respectively. λ_{df} is the flux linkage due to the rotor magnet linking the stator.

The electric torque is

$$T_e = 3\,p\,[\lambda_{df}\,i_q + (L_d - L_q)\,i_d\ i_q\,]/2 \ (5)$$

And the equation for the motor dynamic is

$$T_e = T_L + B\omega_r + J\,p\omega_r\,.\ (6)$$

P is the number of pole pairs, T_L is the load torque, B is he damping coefficient, ω_r is the rotor speed, and J is the moment of the inertia. The inverter frequency is related to the rotor speed as follows:

$$\omega_s = p\,\omega_r\,.\ (7)$$

The machines model is nonlinear as it contains product terms such as speed with i_d and i_q. Note that ω_r, i_q and i_d are state variables.

For dynamic simulation, the equation of the PMSM presented in (1)-(6) must be express in state-space form as shown in (8) - (10):

$$p\,i_d = (V_d - R\,i_d + \omega_s\,L_q\ i_q)/L_d \quad (8)$$

$$p\, i_q = (V_q - R\, i_q - \omega_s\, L_d\; i_d - \omega_s\, \lambda_{df}) / L_q \quad (9)$$

$$p\, \omega_r . = (T_r - T_L - B\, \omega_r) / J. \quad (10)$$

The analysis of PMSM normally results in a good number of simultaneous of non-linear equations which are algebraically complicated, however, and their solution may be cumbersome. Mathematical transformations are tools which make complex system simple to analyze and solutions easy to find. Therefore, by this transformation [1, 9,] the analysis is simplified by a change of variable for current, voltage and flux linkage. The d, q variable are obtained from a, b, c variable through the park transform define bellow:

$$\begin{bmatrix} v_q \\ v_d \\ v_o \end{bmatrix} = 2/3 \begin{bmatrix} \cos(\theta) & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ \sin(\theta) & \sin(\theta - 2\pi/3) & \sin(\theta + 2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (11)$$

The a, b, c, variables are obtained from the d, q variables through the inverse of the park transform defined below:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 1 \\ \cos(\theta - 2\pi/3) & \sin(\theta - 2\pi/3) & 1 \\ \cos(\theta + 2\pi/3) & \sin(\theta + 2\pi/3) & 1 \end{bmatrix} \begin{bmatrix} v_q \\ v_d \\ v_o \end{bmatrix} \quad (12)$$

Note that, transformation apply equally well in current and in the linkages, the total input power to the machine in term of the a, b, c variables.

$$\text{Power} = v_a\; i_a + v_b i_b + v_c i_c \quad (13)$$

While in d, q variables,

$$\text{Power} = 3\,(v_d\, i_d = v_q\, i_q) / 2 \quad (14)$$

Balance system.

MODELING AND DYNAMIC PERFORMANCE OF PULP MILL PMSM WITH DAMPER WINDINGS

In modeling of PMSM with damper winding, it is convenient to split the system into Electrical mode and Mechanical mode.

Electrical model of PMSM with damper windings

The continuous-time electromechanical model of PMSM in second order and non-linear with possible states being the current and fluxes [5, 7], with the assumption that the variation of flux induced by the rotor magnet in the stator must be sinusoidal and the variation of the inductance as a function of the rotor position must also be sinusoidal, the PMSM with damper windings equations expressed in the rotor reference frame become:

$$V_d = R_s i_d + L_d \frac{di_d}{dt} - \frac{L_q}{L_d} P\; \omega_m\; i_q \quad (15)$$

$$V_q = R_s i_q + L_q \frac{di_q}{dt} + \mathrm{P} l_d \omega_m i_d + \omega_m \lambda \quad (16)$$

Expressing equation (15-16) in state variable form with current as state variable

We have,

$$\frac{d}{dt}\, i_d = \frac{1}{L_d} V_d - \frac{R}{L_d} i_d + \delta P\; \omega_m\; i_q \quad (17)$$

$$\frac{d}{dt}\, i_q = \frac{1}{L_q} V_q - \frac{R}{L_q} i_q - \left(\frac{1}{\delta}\right) P\; \omega_m\; i_{d} - \frac{1}{L_q}\; \mathrm{P} \lambda \omega_m \quad (18)$$

The saliency ratio is defined as,

$$\delta = \frac{L_q}{L_d} \quad (19)$$

The d-q axes of the current vector are computed through a state transformation of the stator currents phase i_{as} i_{bs} and i_{cs} [1, 5, 6].

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\omega & \sin\omega \\ -\sin\omega & \cos\omega \end{bmatrix} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} \quad (20)$$

Similarly, the three phase voltages V_{as}, V_{bs} and V_{cs} applied to the PMSM with damper windings are obtained from V_d and V_q voltages by means of the reverse park transformation.

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \cos\omega & -\sin\omega \\ \sin\omega & \cos\omega \end{bmatrix} \begin{bmatrix} V_d \\ V_q \end{bmatrix} \quad (21)$$

The copper loss in the stator windings becomes,

$$P_c = \frac{1}{2} (I^2\; R_s) \quad (22)$$

$$I_2 = i^2\, \mathrm{d} + i^2\, \mathrm{q} \quad (23)$$

The electromagnetic torque of PMSM with damper windings gives rise to two types of torques: One is known as reluctance torque, cause by the saliency phenomenon while the second is the hybrid torque due to interaction between rotor and the stator fluxes [5, 6, 9]

Electromagnetic Torque
T_e = 1.5 P [λ i_q + (L_d - L_q) $i_d i_q$] (24)

The torque components are derived from equation (24),

Hybrid Torque,
T_h = 1.5 P λ i_q (25)

Reluctance Torque,
T_r = 1.5 P (L_d - L_q) $i_d i_q$ (26)

Mechanical model of pmsm with damper windings

The mechanical model of PMSM with damper windings can be represented as a second-order differential equation [5, 6].

$J_m \frac{d^2\theta_m}{dt^2}$ = T_c - T_L (27)

Decomposing equation (27) into two first order differential equation gives,
Pθ_m = ωm (28)

J_m (P ωm) = T_c - T_L (29)
P ωm = $\frac{1}{J_m}$ (T_c - T_L) (30)

But
ωr = ωm P (31)
θ_r = θ_mP (32)

EXPERIMENTAL VERIFICATION OF PMSM

The laboratory experiment conducted in Unipart Research Laboratory on the PMSM with damper windings, the result is as shown in the table1 and figure3

Figure3a: Laboratory Research on PMSM with damper windings (UNIPORT)

Table 2: Pulp mill PMSM with damper windings parameters used for simulation

d-axis inductance,L_d	1.4Mh
q-axis inductance, L_q	2.8mH (1.4mH)
Stator windings R_s	0.6 Ω (1.2 Ω)
Induced flux by magnet	0.12Wb
Number of pole, P	2
Rated Voltage, V	250 V
Rated frequency, f	50Hz
Combined rotor and load inertia, J_m	0.83Kgm^2
Shaft mechanical torque, T_l	3.2Nm

Source [1]

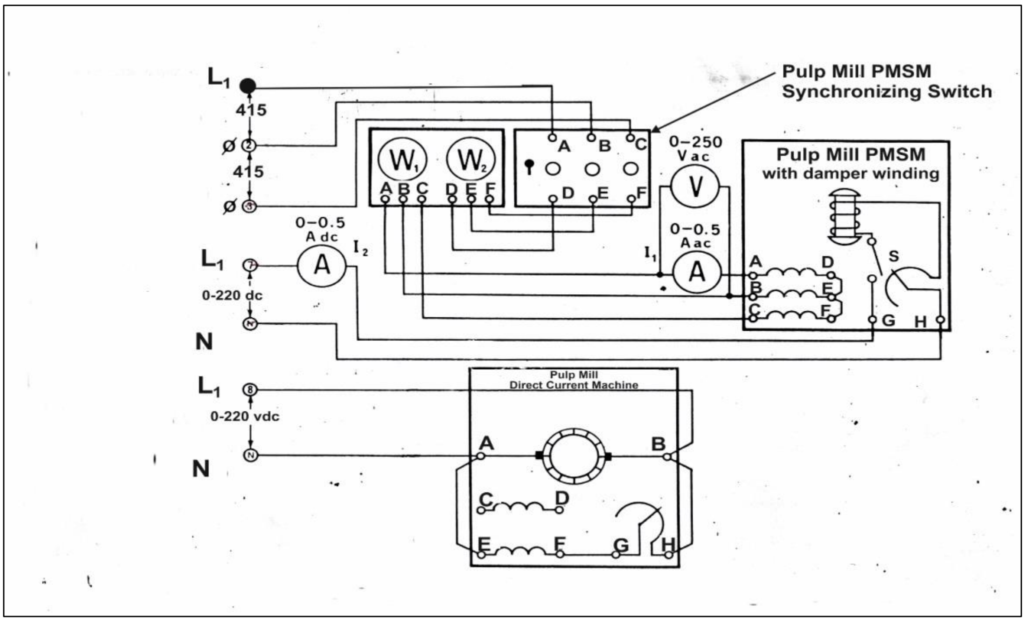

Figure3b: Electrical Laboratory Research on PMSM with damper windings circuit diagram

Table 2a: Result of experimental on pmsm with damper windings

I2 (AMPS)	E1 (VOLTS)	I 1 (Amp)	POWER (VA)	W1	W2	POWER (Watts)	PF
0	250	0.85	298	-57	124	77	0.24
0.2	250	0.67	245	-47	103	66	0.26
0.4	250	0.51	176	-27	80	63	0.33
0.6	250	0.29	96.4	20	50	60	0.59
0.8	250	0.19	60.4	35	35	60	0.99
1.0	250	0.25	82.0	50	20	60	0.71
1.2	250	0.40	136	76	-22	64	0.44
1.4	250	0.57	197	90	-34	66	0.31
1.6	250	0.73	255	110	-45	75	0.28

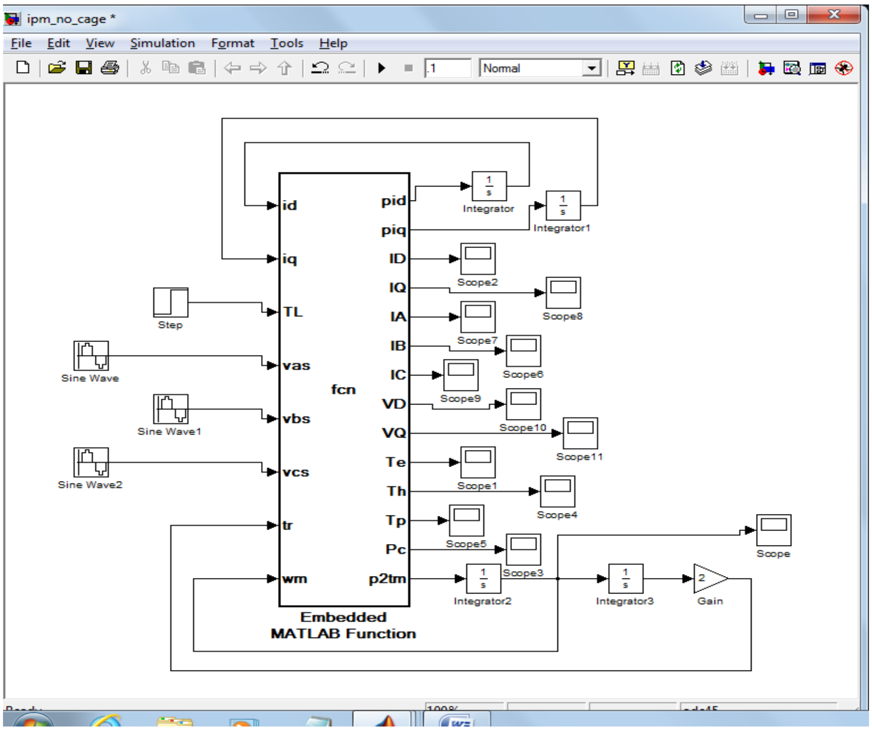

Figure 4: Simulation Simulink Pulp mill PMSM with damper windings block-diagram

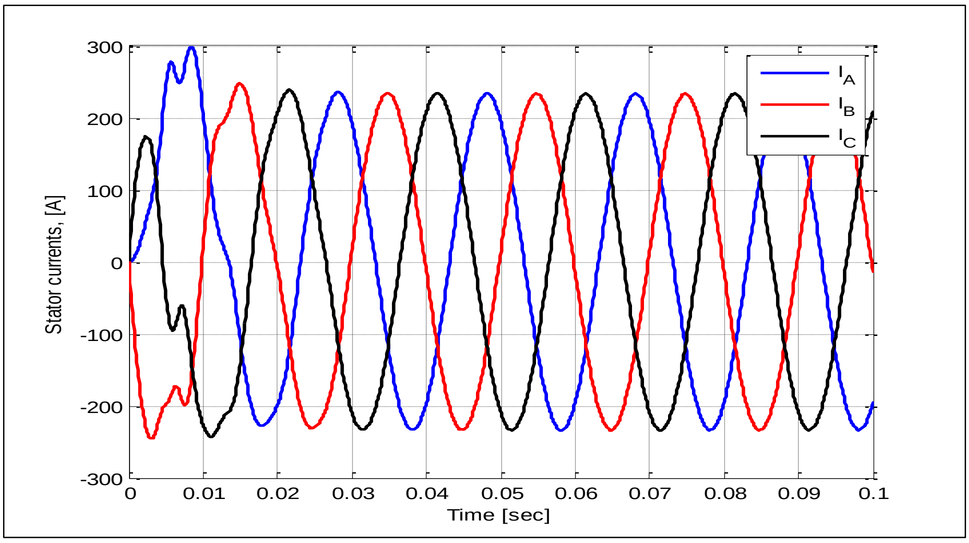

Figure 5: Pulp mill PMSM with damper windings stator current(A) versus time(s)

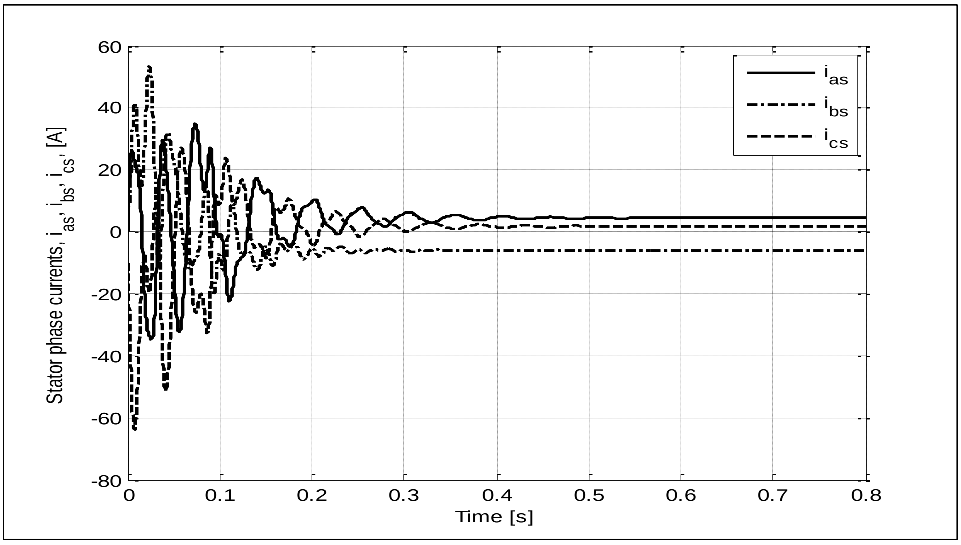

Figure 6: Pulp mill PMSM with damper windings Stator Phase Currents/time at run- up Condition

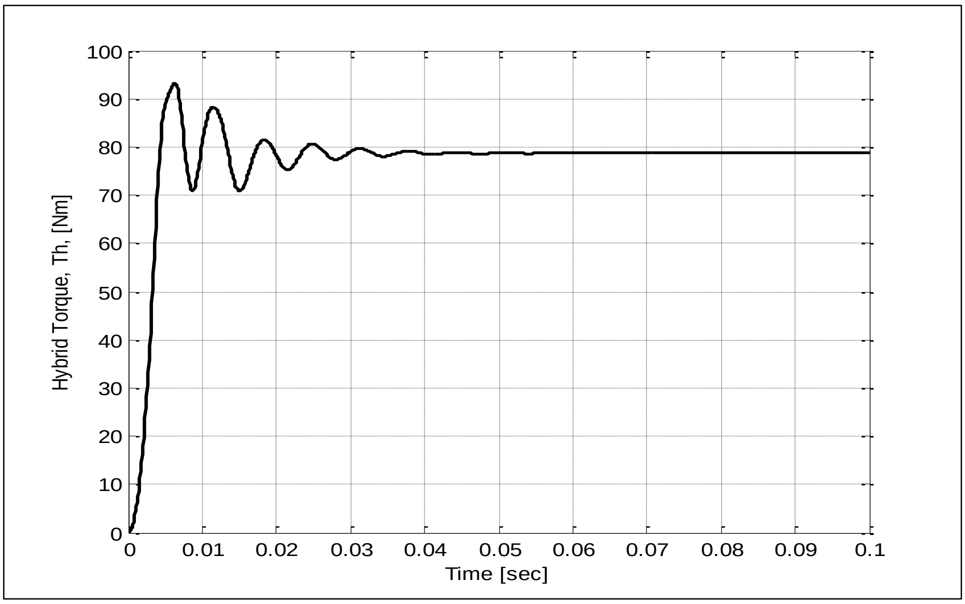

Figure 7: Pulp mill PMSM with damper windings Hybrid Torque versus Time

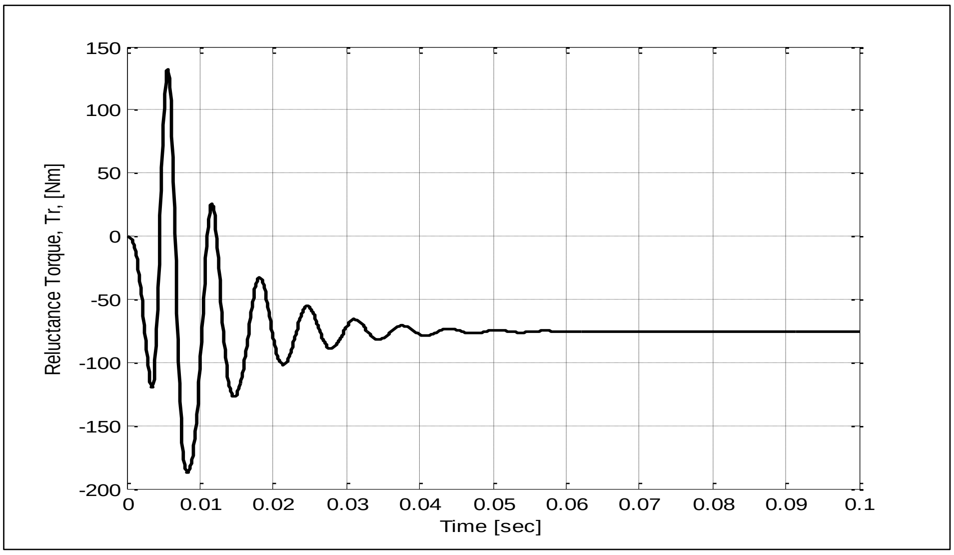

Figure 8: Pulp mill PMSM with damper windings Reluctance Torque versus time

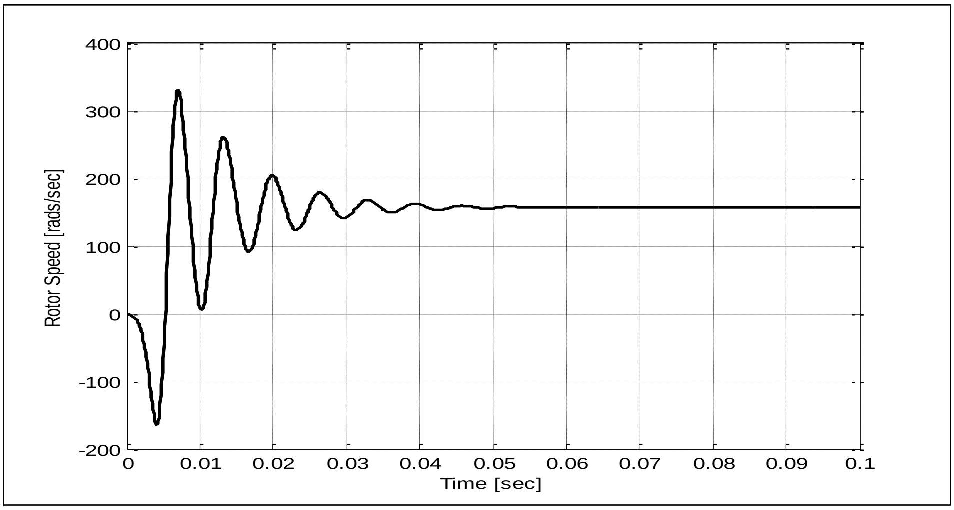

Figure 9: Pulp mill PMSM with damper windings Rotor Speed versus time

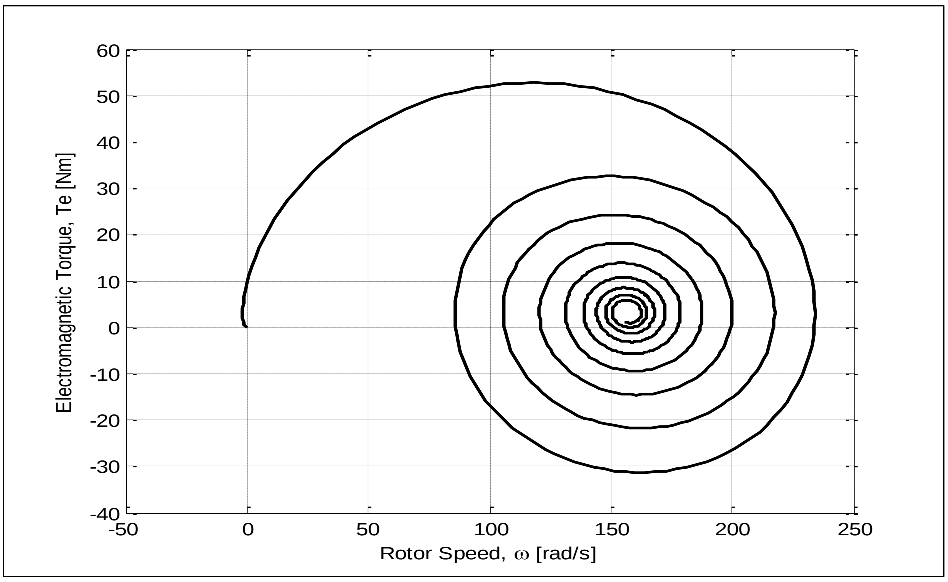

Figure 10: Pulp mill PMSM with damper windings electromagnetic torque versus rotor Speed

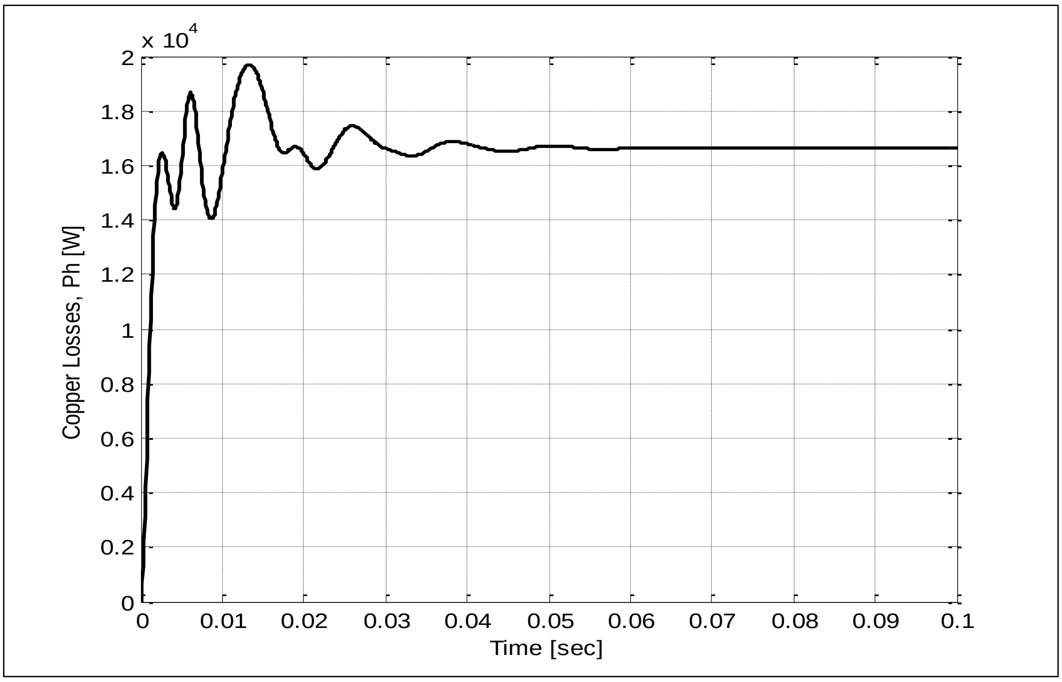

Figure 11: Pulp mill PMSM with damper windings copper losses versus time (s)

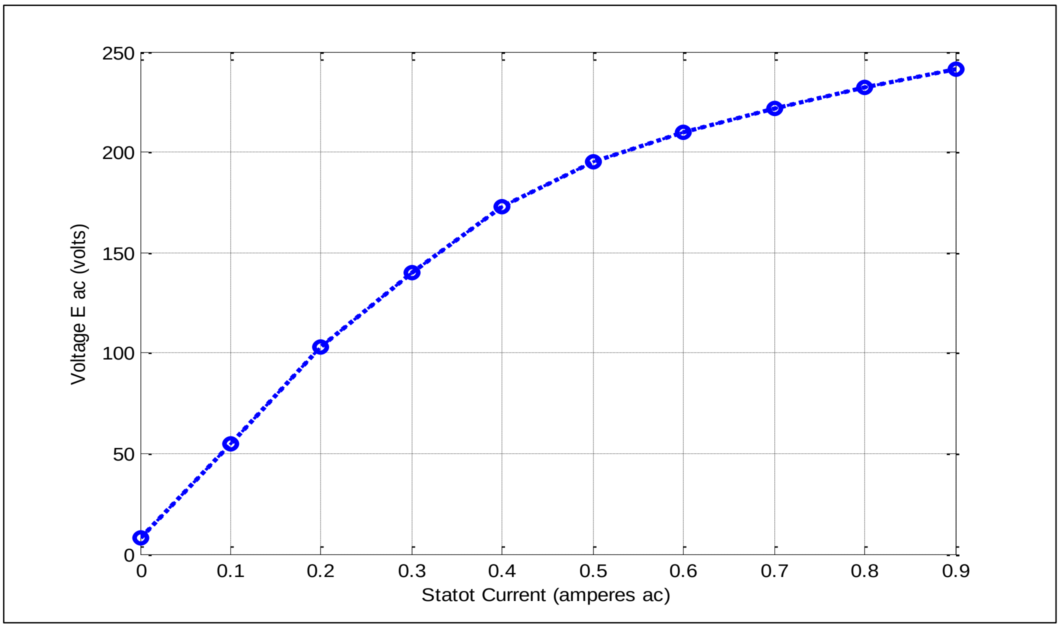

Figure 12: Pulp mill PMSM with damper windings Graph of Voltage (V ac) versus Current (I)

Experimental verification of the drives performances was given and the result of simulation of the run-up characteristics of pulp mill plant PMSM with damper windings has been presented for machines dynamic performance studies. The figures present time function of the stator line current, time function of the electromagnetic torque, the reluctance torque to the motor torque was higher than that of the hybrid, torque. (50Nm and 130Nm) respectively, this is understandable since the salience ratio δ is 2. The q-axis current lags behind the d-axis current but with a higher peak current, the d-axis current exhibits prolonged oscillation compare to the q-axis current, The time function of the rotor speed was observed that the motor attains maximum rotor speed at 340 rad/s in about 5.3ms. At about 40ms, the motor attains a steady-state speed of 150 rad/s. The electromagnetic torque and the rotor speed shows the trend of the copper losses in PMSM with damper windings under test and at 8.2ms the copper loss was maximum and falls to its steady-state value (≈1.8W) 30ms after start up.

The effect of saliency factor on the dynamic performance of the test pulp mill plant-machines shows that the value of the q-axis inductance when reduced to half of its rated value. It has effect on the electromagnetic torque, rotor speed and copper losses at a unity saliency factor of Lq = 1.4mH, both the magnitude of the electromagnetic torque, hybrid torque and the rotor speed are lowered and the copper losses increased with sustained stead state oscillation. Increase in the stator windings resistance decrease the first peak of the electromagnetic torque, rotor speed and copper losses. Since copper losses are dependent on stator windings resistance, an increase was expected in the magnitude of copper losses due to increase in Rs. But the reverse was the case. This is as a result of decrease in the magnitudes of both the d-axis and q-axis currents to which the copper losses are also dependent.

The result of the parameter variations show that the pulp mill plant dynamic performance of PMSM with damper windings was highly sensitive to rated voltage, stator resistance and equivalent field current value. These parameters must be checked and properly regulated during machine design. The simulation results are were depicted and presented graphically for machine dynamic behavior evaluations.

CONCLUSION

The dynamic d-q modeling of the system was used to study of machines transient states variables and as well as the steady state conditions. It was achieved by converting the three phase voltages and currents to d-q axis variables by using the Parks transformation and equivalent circuit for proper machines simulation. It was achieved and derived from the d-q modeling of the machines using the voltage equations of the stator. From the assumption, rotor d axis flux was represented by a constant current source which described equations of λf, (field flux linkage), Ldm, d-axis (magnetizing inductance), if, (equivalent permanent magnet field current).

Pulp mill plant PMSM with damper windings was operated without any additional technical equipment but only the addition of damper windings to run the machine up to the speed of the synchronous machines action with the machine pulling into synchronism by the combination of the reluctance and synchronous motor torque provided by the magnet. During the start-up, the magnet exerts a braking torque that opposes synchronous motor type torque provided by the damper windings. The torques provided by the damper windings overcomes the magnetic braking torque in addition to the load and friction to ran the pulp mill plant PMSM with damper windings successfully. Experimental verification of the drives performances was given and the result of simulation of the run-up characteristics of pulp mill PMSM with damper windings has been presented. The solution has been obtained by solving numerically the set of non-linear differential equations governing both the electrical and the mechanical models of the machines for dynamic performance studies, using the Matlab/Simulink including block diagram method. This is recommended for pulp mill plant designers, engineers, technicians, operator and product manufacturers.

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