Dynamic Performance of Permanent Magnet Synchronous Machines in Cognate Plant Using Selsyn Control

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Abstract- The dynamic performance of Permanent magnet synchronous machine (PMSM) in cognate plant using selsyn control is presented. The PMSM is an alternating current machine whose excitation is provided by the permanent magnet, and used in a wide range of variety of cognate plant applications, like, machine tools, robotics, and electric vehicles. This is because of its high performance of permanent magnet (PM) residual magnetism, that make it possible for the PM to have a superior power density, torque to inertia ratio and efficiency, compared to conventional machines. Selsyn is an electromagnetic device attached to PMSM is used to transmit angular positioning data to a remote location device to one or more indicator located far away from the transmitting plant area. It is like electric motor. Selsyn has primary windings on the rotor and secondary windings on the stator. It is used for winding direction, Antenna direction indicator and remote position controller. Experimental on these drives performances is given and simulation result of the run-up characteristics using selsyn control is presented in this paper. The numerically set of non-linear differential equations governing both the electrical and the mechanical models was solved using Runge-Kutta fourth-order method. Parameter variations show that the dynamic performance of PMSM in cognate plate using selsyn control is highly sensitive to rated voltage, stator resistance and equivalent field current value. The performances results were depicted graphically for machines dynamic study. This is recommended for used in variety of industrial applications, like, machine tools, robotics, and electric vehicles, winding direction, Antenna direction indicator and remote position controller.

I. INTRODUCTION

Selsyn is an electromagnetic device used for transmit angular positioning data to a remote location device to indicator located far away from the transmitting plant area. It is an electric motor. Selsyn has primary windings on the rotor and secondary windings on the stator and attached to Permanent magnet synchronous machines (PMSM) as an ac machine whose excitation is provided by permanent magnet, and is being used increasingly in a wide range of applications, includes: machine tools, robotics, aerospace generators, actuators and electric vehicles, winding direction, Antenna direction indicator and remote position controller. This has been possible with the advent of high performance of permanent magnet (PM) with the creativity and residual magnetism, which make it possible for the PM to have a superior power density, torque to inertia ratio and efficiency [1]. PMSM does not require DC supply excitation circuit nor do they have slip ring and contact brushes. The direct current in the rotor field is fed through the slip ring provided by the brushless exciter on the same shaft. [2].

Selsyn is an electrical repeating device having same working principle and construction like that of induction machines [8]. It performs entirely function such as speed positioning, monitoring, length counting by operating as an electrically interconnected pair designated as transmitters and receivers. Selsyn system transmits exact duplication of mechanical motor between separate location using wires instead of shaft. Selsyn transmitter and receivers are connected together by the uses of wires and excited from the source. Selsyn transmitters convert mechanical motion into electrical signal and vise visa for selsyn receivers. The rotor windings is connected to a single phase ac power supply, the stator windings is connected to each other and PMSM, see connections as shown in figure 1.

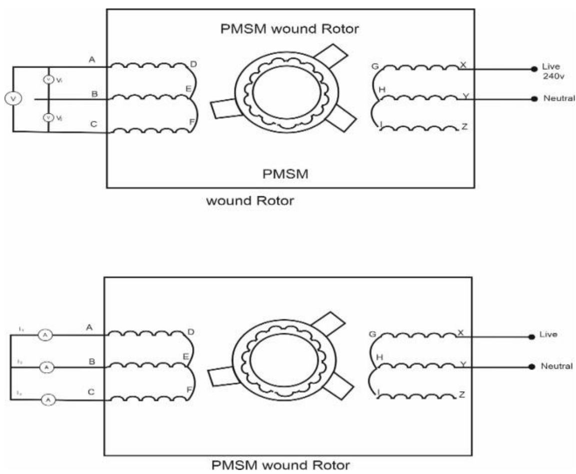

figure 1a: Connection of selsyn Rotor and windings

PMSM with selsyn control is a rotating electric machine where the stator is classic, three phase stator like that of induction machines and the rotor has prominent magnets. A PMSM with selsyn control 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 [2, 7, 6].

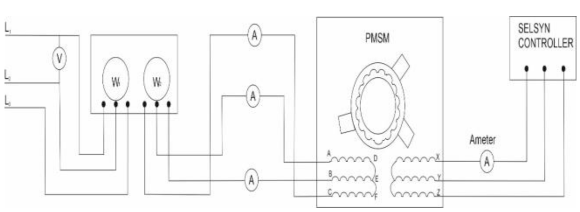

Figure 1b: PMSM with selsyn control circuit

The numerically set of non-linear differential equations governing both the electrical and the mechanical models of PMSM in cognate plate using selsyn control was solved for dynamic studies, using Runge-Kutta fourth-order method. The method estimates the desirable torque to track mechanical torque at fixed speed operation of PMSM with selsyn control.[3] This method is not time consuming; this implies that rotor losses and regular brushes maintenance, moving to the field for data, which implies downtime. Note that the key reason for developing PMSM [2] was to remove the foregoing disadvantages of the SM by replacing its field coils, dc power supply, and slip ring with permanent magnet. the dynamic performance of PMSM with selsyn control differential equation are expressed in rotor reference frame with flux linkage as state variable. The effect of the PMSM with selsyn control parameter variation was investigated in the Uniport cognate Plant figure 2.

Figure 2: Uniport Micro-cognate plant (EEE Laboratory)

Uniport cognate plant has the following components: PMSM, Three phase wattmeter, Variable Power supply unit (0-250V), AC Ammeter (2.5A), AC Voltmeter (250V), DC Voltmeter (2.5V), selsyn receivers, selsyn transmitters, radar antenna, rotating mast and Connection leads. Figure 3 and 4

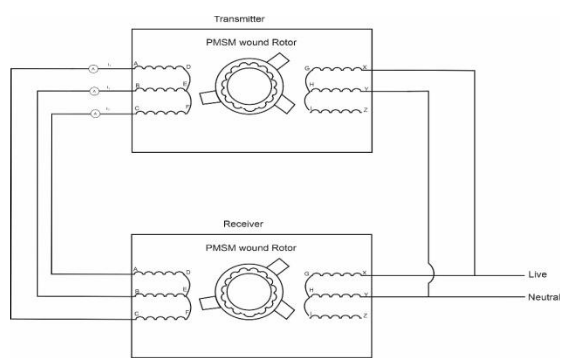

Figure 3: Selsyn control Transmitter and Receivers.

The circuit is connected as shown in figure1b, the stator winding is connected through the wattmeter to the fix 240V, three phase output of the power supply terminals, the rotor winding is connected through the ammeter to the variable 0-240V DC output power supply terminal. Voltage was adjusted to zero by means of control knob. While the switch must remain open. The field rheostat was also adjusted to zero resistance by turning the control knob full clockwise.

Power supply was turn 'ON' and the motor start running and values were recorded see table 2.

The rotor of transmitter turns through a small angle when it is rotating, the voltage is induced into the stator windings of transmitters, at this point, they are no longer identical to the receivers. The unbalanced caused the voltage to circulate in the stator windings. The magnetic field is set up forcing the rotor of the receivers to up the same position in the rotor of the transmitters.

The power supply to selsyn transmitter is connected to terminal X and Y figure 3 to a variable output unit live and neutral. The power supply was turn ON and adjusted to 50volts. The voltmeter results were recorded as the rotor shaft rotates the stator voltages also vary until it reaches the maximum value. See table 2.

The same procedure for current record as shown figure 1

The result shows that the magnitude of the field current (fm), the supply voltage and the stator resistance play a very important role in the dynamic performance of PMSM with selsyn control for improve performance.

PMSM has remain vital in industrial application due to its numerous advantages over other machines that are conventionally used for ac drives [10], thus, high efficiency, compactness, power density, fast dynamic, high torque to inertia ratio. The use of permanent magnet in the rotor of PMSM with selsyn control makes it unnecessary to supply magnetizing current through the stator for constant air-gap flux, the stator current need only be torque producing. Hence the PMSM with selsyn control will operate at a high-power factor [4, 5, 6, 9.].

The possibility of using the PMSM with selsyn control has been examined. It is recognized that with the rotor position feedback, the motor can be held in synchronism[5].

II. REMOTELY LOCATED CONTROL ROOM ARRANGEMENT

The stator winding of the figure 3 is connected to each other. The rotor is parallel and are connected to 240v power supply live and neutral. The power was adjusted to 200volt ac. An appreciable torque was noted. The figure4 show the mean of transmitting the instantaneous angular position of arevolving radar antenna to an indicator in a remotely located control room.

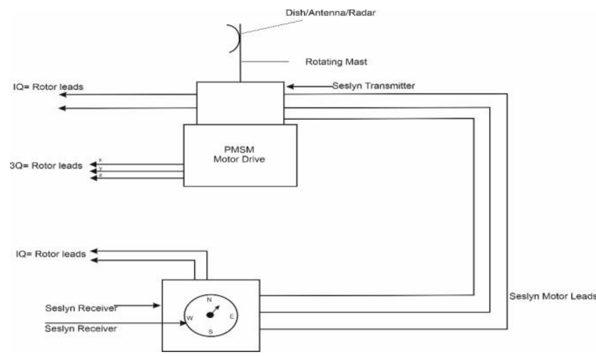

Figure 4: Transmission of Instantaneous Angular position of a Revolving Radar Antenna to an Indicator in a Remote Located Control Room

III. EQUIVALENT D-Q CIRCUIT MODEL OF THE PMSM

Equivalent d-q model of PM machine shows in figure 5(a & b) 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 [3, 7, 8]. 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 figure5.

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 [5, 8, 10 Essentially resistance Rm connected across the d-axis magnetization inductance Lmd show this effect [4,5,8]. There is no leakage inductance in the field.

IV. ELECTRICAL MODELING

The d-q axis representation of a PMSM when the reference frames in the rotor given by[3, 9]

$$v_q = r_s i_q + \frac{d\lambda_q}{dt} + \lambda_d \ \omega r \quad (1)$$

$$v_d = r_s i_d + \frac{d\lambda_d}{dt} - \lambda_q \omega r \quad (2)$$

$$0 = r_{kq} i_{kq} + \frac{d\lambda_{kq}}{dt} \quad (3)$$

$$0 = r_{kd} i_{kd} + \frac{d\lambda_{kd}}{dt} \quad (4)$$

Expressing equations (1-4) in state variable form with flux linkages, we have

$$\dot{\boldsymbol{\lambda}}_{\boldsymbol{q}} = v_q - \omega_r \lambda_d + \frac{r_s}{L_{ls}}(\lambda_{mq} - \lambda_q) \quad (5)$$

$$\dot{\boldsymbol{\lambda}}_{\boldsymbol{d}} = v_d + \omega_r \lambda_q + \frac{r_s}{L_{lx}}(\lambda_{md} - \lambda_d) \quad (6)$$

$$\dot{\lambda}_{kq} = \frac{r_{kq}}{L_{lkq}}(\lambda_{mq} - \lambda_{kq}) \quad (7)$$

$$\dot{\lambda}_{kd} = \frac{r_{kd}}{L_{lkd}}(\lambda_{md} - \lambda_{kd}) \quad (8)$$

Where

$$\lambda_{mq} = L_{MQ}\left(\frac{\lambda_q}{L_{ls}} + \frac{\lambda_{kq}}{L_{lkq}}\right) \quad (9)$$

$$\lambda_{md} = L_{MD}\left(\frac{\lambda_d}{L_{ls}} + \frac{\lambda_{kd}}{L_{lkq}} + i_{fm}\right) \quad (10)$$

$$L_{MQ} = \frac{(L_{mq} L_{lkq} L_{ls})}{(L_{lkq} L_{ls} + L_{mq} L_{ls} + L_{mq} L_{lkq})} \quad (11)$$

$$L_{MD} = \frac{(L_{md} L_{lkd} L_{ls})}{(L_{lkd} L_{ls} + L_{md} L_{ls} + L_{md} L_{lkd})} \quad (12)$$

$$L_d = L_{ls} + L_{md} \quad (13)$$

$$L_q = L_{ls} + L_{mq} \quad (14)$$

$$i_q = \frac{\lambda_q - \lambda_{mq}}{L_{ls}} \quad (15)$$

$$i_d = \frac{\lambda_d - \lambda_{md}}{L_{ls}} \quad (16)$$

$$i_{kq} = \frac{\lambda_{kq} - \lambda_{mq}}{L_{lkq}} \quad (17)$$

$$i_{kd} = \frac{\lambda_{kd} - \lambda_{md}}{L_{lkd}} \quad (18)$$

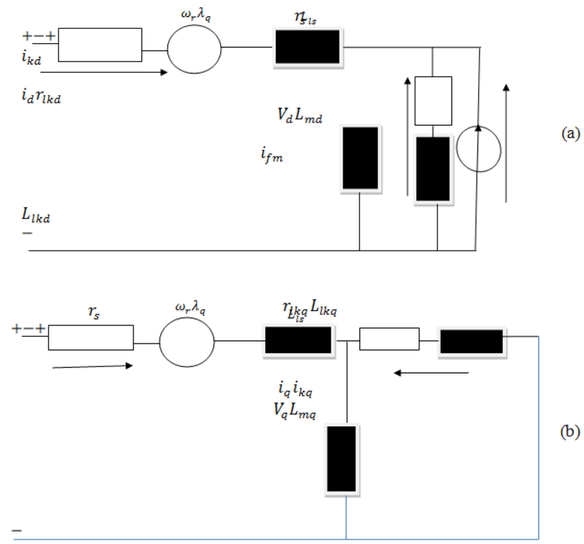

Figure5: Equivalent circuit of (a) Quadrature Axis (b) Direct Axis (b)Quadrature Axis of permanent magnet synchronous machine with selsyn control using the derived equations.

The three main components of PMSM torque are: reluctance torque, Synchronous torque, Excitation torque.

PMSM Motor torque

$$T_{em} = 1.5\ \mathrm{p}\ (\lambda_d i_q - \lambda_q \ i_d) \quad (19)$$

PMSM Reluctance Torque

$$T_r = 1.5\ P\ (L_d - L_q) i_d i_q \quad (20)$$

PMSM SynchronousTorque

$$T_{syn} = 1.5\ \mathrm{P}\ (L_{md}\ i_{kd} i_q - L_{mq}\ i_{kq} i_q) \quad (21)$$

PMSM Excitation Torque

$$T_{ex} = 1.5\ \mathrm{P}\ L_{md}\ i_{fm} i_q \quad (22)$$

Where P are pole pairs, assumed the line voltage are balanced,

The d-q voltages in terms of the load angle become,

$$V_d = -V\sin\delta \quad (23)$$

$$V_d = V\cos\delta \quad (24)$$

Stator phase current is related to the d-q currents [3, 9].

$$i_{ax} = i_q$$

$$i_{bx} = -\frac{1}{2} i_q - \frac{1}{\sqrt{3}} i_d \quad (25)$$

$$i_{cx} = -\frac{1}{2} i_q + \frac{1}{\sqrt{3}} i_d \quad (26)$$

V. MECHANICAL MODEL

The mechanical model of the PMSM which allows the inertia and mechanical load torque to be incorporated, swing equation equations (27-28),

$$\dot{\delta} = \omega_b - \omega_r \quad (27)$$

$$\dot{\omega_r} = \frac{p}{jm} (T_{em} - T_L) \quad (28)$$

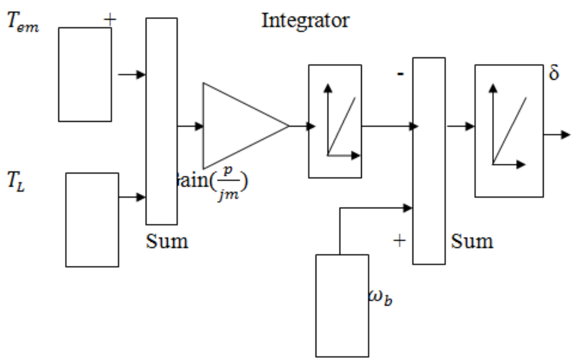

Figure 6: Mechanical model block diagram of PMSM with Selsyn Control

Table 1: PMSM with selsyn control parameters

Stator leakage inductance	2.59Mh
q-axis rotor leakage inductance	40.61Mh
d-axis rotor resistance	0.8113Ω
q-axis rotor resistance	1.6226Ω
q-axis magnetizing inductance	40.69Mh
d-axis magnetizing inductance	19.05mH
d-axis rotor leakage inductance	18.97Mh
Load torque	7.63Nm
Motor inertial	0.01986Kgm^2
Rated voltage	230V(208V, 255V)

Source: [5]

TABLE2a: RESULT OF EXPERIMENTAL ON PMSM WITH SELSYN CONTROL

I2 (AMPS)	E1 (VOLTS)	I 1 (Amp)	POWER (VA)	W1	W2	POWER (Watts)	PF
0	2O8	0.80	288	-47	114	67	0.23
0.1	208	0.62	235	-37	93	56	0.25
0.2	208	0.46	166	-17	70	53	0.32
0.3	208	0.24	86.4	10	40	50	0.58
0.4	208	0.14	50.4	25	25	50	0.99
0.5	208	0.20	72.0	40	10	50	0.70
0.6	208	0.35	126	66	-12	54	0.43
0.7	208	0.52	187	80	-24	56	0.30
0.8	208	0.68	245	100	-35	65	0.27

The experiment was carried out in the University of Port Harcourt Power and Machine Laboratory with a standard machine see Figure 1: Uniport Micro-cognate plant

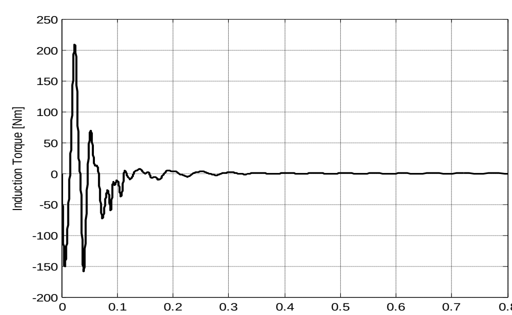

Figure 7: Graph of PMSM Torque against time with Selsyn Control at run-up Condition.

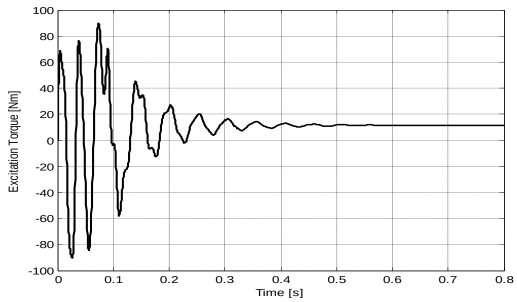

Figure 8: Graph of PMSM Excitation Torque against time with Selsyn Control at run-up Condition

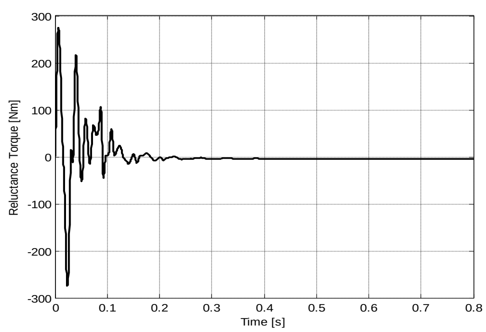

Figure 9: Graph of PMSM Reluctance Torque against time at run-up Condition.

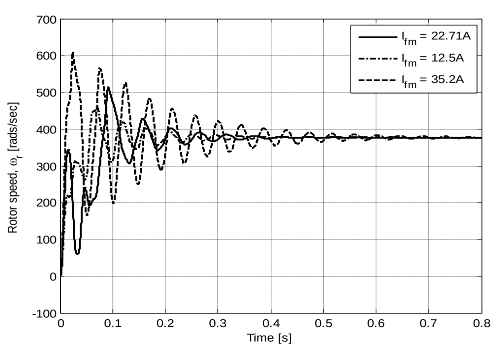

Figure 10: Graph of PMSM Stator Phase Currents against time with Selsyn Control at run-up Condition.

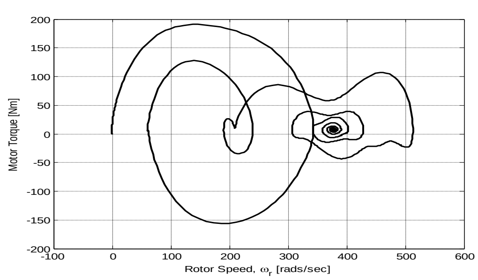

Figure 11: Graph of PMSM Torque against Rotor Speed with Selsyn Control at run-up Condition.

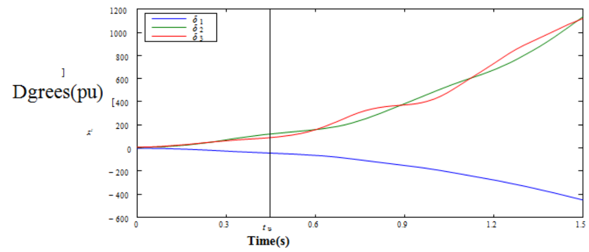

Figure 12: Graph of Load angle against Time for Varying Stator Resistance

TABLE 2b: PMSM voltages generated and measured across each stator windings

I1amps)	E1(volts)	E2(volts)	E3(volts)	Eac(avg)
0	9	7.5	8	8.2
0.1	58	52	55	55
0.2	105	100	103	103
0.3	142	138	140	140
0.4	175	170	175	173
0.5	198	192	195	195
0.6	212	208	210	210
0.7	225	220	220	222
0.8	235	230	230	232
0.9	+245	+238	+240	241

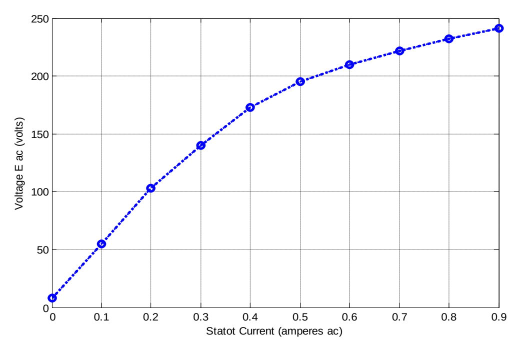

Figure 13: Graph of Voltage (V ac) against Current (I)

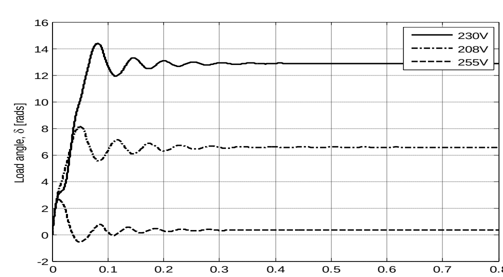

Figure 14: Graph of Load angle against Time for Varying Rated Voltage.

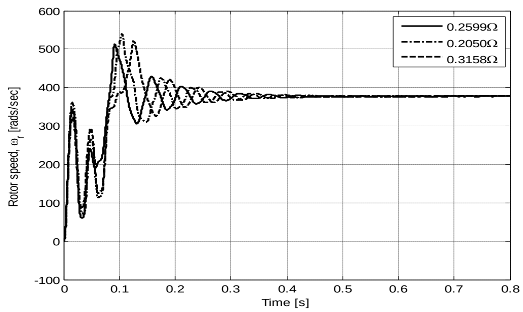

Figure 15: Graph of Rotor Speed against Time for Varying Stator Resistance.

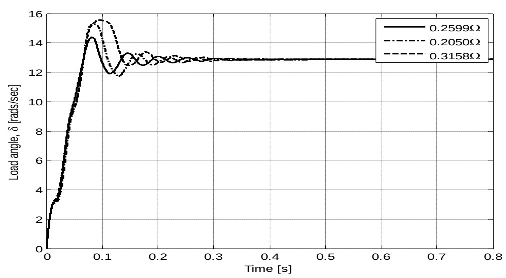

Figure16: Graph of Load angle against Time for Varying Stator Resistance.

The effect of varying the stator resistance on the transient performance of the PMSM with selsyn control. At lower values of the stator resistance, the motor possesses initial peak magnitude of the rotor speed and motor torque. The maximum load angle is attained at high value of the stator resistance. also shown that as the equivalent field current increases, the rotor speed and the rotor torque become more pulsation in nature. The effect of varying the equivalent field current was investigated. Varying the equivalent field current above or below the rated value, forces the load angle to drop considerably.

CONCLUSION

The rotor turns each stator current and will in turn momentary peak to some maximum value depending upon the braking torque and then fall to zero. Receivers and Transmitters of selsyn control will operate separate as long as the three connecting stator leads are of heavy gauge to keep losses to a minimum, it will work at any distance.

The motor torque-rotor speed relationship at run-up condition as shown in Figures, the torques of PMSM with selsyn control, the initial magnitude of the reluctance torque is greater than the others, the reluctance, gradually varnishes after about 0.2s from start-up. The transient stator phase currents are very high, especially in phase c and phase b. At about 0.3s, as the stator phase currents reach their steady state values. The motor torque-rotor speed relationship at run-up characteristic of the system is highly cyclic. The effect of varying the rated voltage beyond the rated value of the machines is that, increase in the voltage lead to increase in the speed and motor torque, but with a decrease in the motor load angle. This is recommended for used in variety of industrial applications, like, machine tools, robotics, and electric vehicles, winding direction indicator, Antenna direction indicator and remote position controller.

Future advances in PMSM with selsyn control in technology will reduce the capital cost, existing market will grow and the new market will open up.

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