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MODELLING THE OPERATION OF A PARMANENT MAGNET SYNCHRONOIUS MACHINE

ABSTRACT: recent studies Have discovered that the permanent magnet synchronous machines could be serious competitors to induction motor in servo applications, it consists of stator and a rotating part requiring only AC supply for its operation. The use of the PMSM combines with the direct torque scheme offers many opportunities to achieve rapid and accurate torque control in servo application. Their operation is similar to that of normal synchronous motors with the stator creating the magneto motive force. PMSM are increasingly applied in several areas such as generations, tractions and automobiles robotics and aerospace technology.

INTRODUCTION: in a permanent synchronous machine the rotor winding is replaced by permanent magnets, a permanent magnet synchronous machine is basically ordinary ac machine with windings distributed in the stator slots so that the flux created by stator current is approximately sinusoidal. Permanent magnet drives are replacing classic dc and induction machine drives in a variety of industrial applications such as industrial robots. Synchronous machines being an electrical transducer converting mechanical energy into electrical energy and vice versa obey the Law of Electromagnetic induction and the Law of interaction. They require external means to bring their speed close to synchronous speed for synchronization to occur. The permanent magnet synchronous machine. The permanent magnet synchronous machines (PMSM) requires only AC supply for its operation. PMSM can be classified based on the direction of field flux into Radial field and axial field. The flux direction is along the radius of the machine in radial field. They are most commonly used. In axial field however, the flux direction is parallel to the rotor shaft.

MODE OF OPERATION: In general, synchronous generator consists of two parts rotor and stator. The rotor part consists of field poles and stator part consists of armature conductors. The rotation of field poles in the presence of armature conductors induces an alternating_voltage which results in electrical power generation. The speed of field poles is synchronous speed and is given by

$$Ns = \frac{120f}{p}$$

Where, ‘f’ indicates alternating current frequency and ‘P’ indicates number of poles.

The principle of operation of synchronous generator is electromagnetic induction. If there exits a relative motion between the flux and conductors, then an emf is induced in the conductors. To understand the synchronous generator working principle, let us consider two opposite magnetic poles in between them a rectangular coil or turn is placed.Rectangular Conductor placed in between two opposite Magnetic Poles If the rectangular turn rotates in clockwise direction against axis a-b as shown in the below figure, then after completing 90 degrees rotation the conductor sides AB and CD comes in front of the S-pole and N-pole respectively. Thus, now we can say that the conductor tangential motion is perpendicular to magnetic flux lines from north to south pole.

MODELLING OF A PMSM:

In modelling of a PMSC, the transient and steady-state behaviour in electrical and mechanical subsystems must be considered. The Electrical properties involve the steady state and transient relations between the machine voltages, currents and flux linkages. Mechanical properties have to do with the rotor speed, electromagnetic torque and motion resistance. (Power Electronics and Power Systems, n.d.)

Using the Park’s transformation: Using a three phase synchronous machine with voltages Va, Vb, Vc in the direct (d-axis) axis and quadrature (q-axis) axis, the transformation is given as:

Vdq0 = T * Vabc ---- (1)

Where

$$[T] = \frac{2}{3}\begin{bmatrix} cos\theta r & \cos(\theta r - \frac{2\pi}{3}) & \cos(\theta r + \frac{2\pi}{3}) \\ -sin\theta r & -sin(\theta r - \frac{2\pi}{3}) & -sin(\theta r + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \text{---- (2)}$$

$$[T] = \frac{2}{3}\begin{bmatrix} cos\theta r & \cos(\theta r - \frac{2\pi}{3}) & \cos(\theta r + \frac{2\pi}{3}) \\ sin\theta r & sin(\theta r - \frac{2\pi}{3}) & sin(\theta r + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \text{---- (3)}$$

Calculating for phase voltages

$$Vabc = T^{-1} * Vdq0 \text{ ---- (4)}$$

Calculating T^{-1}

$$T^{-1} = \begin{bmatrix} cos\theta r & sin\theta r & 1 \\ cos(\theta r - \frac{2\pi}{3}) & sin(\theta r - \frac{2\pi}{3}) & 1 \\ cos(\theta r + \frac{2\pi}{3}) & sin(\theta r + \frac{2\pi}{3}) & 1 \end{bmatrix} \text{---- (5)}$$

Using stator equations, the voltages at d-axis and q-axis is expressed as:

$$V_d = \text{Rsid} - \omega\text{rLqiq} + \rho\,(\text{Ldid} + \lambda\text{f}\,) \text{ ---- } (6)$$

$$V_q = \text{Rsiq} + \omega\text{r}\,(\text{Ldid} + \lambda\text{f}) + \rho L_d i_d \text{ ---- } (7)$$

In Matrix form

$$\begin{bmatrix} Vq \\ Vd \end{bmatrix} = \begin{bmatrix} \text{Rs} + \rho\text{Lq} & \omega\text{rLd} \\ -\omega\text{rLq} & \text{Rs} + \rho\text{Ld} \end{bmatrix} \begin{bmatrix} \text{iq} \\ \text{id} \end{bmatrix} + \begin{bmatrix} \omega\text{r}\lambda\text{f} \\ \rho\lambda\text{f} \end{bmatrix} \text{---- } (8)$$

The developed torque equation for a PMSC is derived as

$$Te = \frac{3}{2}\left(\frac{P}{2}\right)(\lambda\text{diq} - \lambda\text{qid}) \text{ ---- } (9)$$

$$Te = Tl + \text{B}\omega\text{m} + \text{J}\frac{\text{d}\omega\text{m}}{dt} \text{ ---- } (10)$$

Solving for ωm

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$$\omega\text{m} = \int\left(\frac{\text{Te} - \text{TL} - \text{B}\omega\text{m}}{\text{J}}\right)dt \text{ ---- } (11)$$

$$\omega\text{m} = \omega\text{r}\left(\frac{2}{P}\right) \text{ ---- } (12)$$

Substituting equation (8) into equation (4)

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = \frac{2}{3}\begin{bmatrix} cos\theta r & sin\theta r & 1 \\ cos(\theta r - \frac{2\pi}{3}) & sin(\theta r - \frac{2\pi}{3}) & 1 \\ cos(\theta r + \frac{2\pi}{3}) & sin(\theta r + \frac{2\pi}{3}) & 1 \end{bmatrix}\left[\begin{bmatrix} Rs + \rho Lq & \omega rLd \\ -\omega rLq & Rs + \rho Ld \end{bmatrix}\begin{bmatrix} iq \\ id \end{bmatrix} + \begin{bmatrix} \omega r\lambda f \\ \rho\lambda f \end{bmatrix}\right] \text{ ----}$$

(13)

OR

OR

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = \frac{2}{3}\begin{bmatrix} cos\theta r & sin\theta r & 1 \\ cos(\theta r - \frac{2\pi}{3}) & sin(\theta r - \frac{2\pi}{3}) & 1 \\ cos(\theta r + \frac{2\pi}{3}) & sin(\theta r + \frac{2\pi}{3}) & 1 \end{bmatrix}\begin{bmatrix} Vq \\ Vd \\ Vo \end{bmatrix}$$

Solving for Vdqo

$$\begin{bmatrix} Vq \\ Vd \\ Vo \end{bmatrix} = \frac{2}{3}\begin{bmatrix} cos\theta r & cos(\theta r - \frac{2\pi}{3}) & cos(\theta r + \frac{2\pi}{3}) \\ sin\theta r & sin(\theta r - \frac{2\pi}{3}) & sin(\theta r + \frac{2\pi}{3}) \\ 0.5 & 0.5 & 0.5 \end{bmatrix}\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \text{ ---- (14)}$$

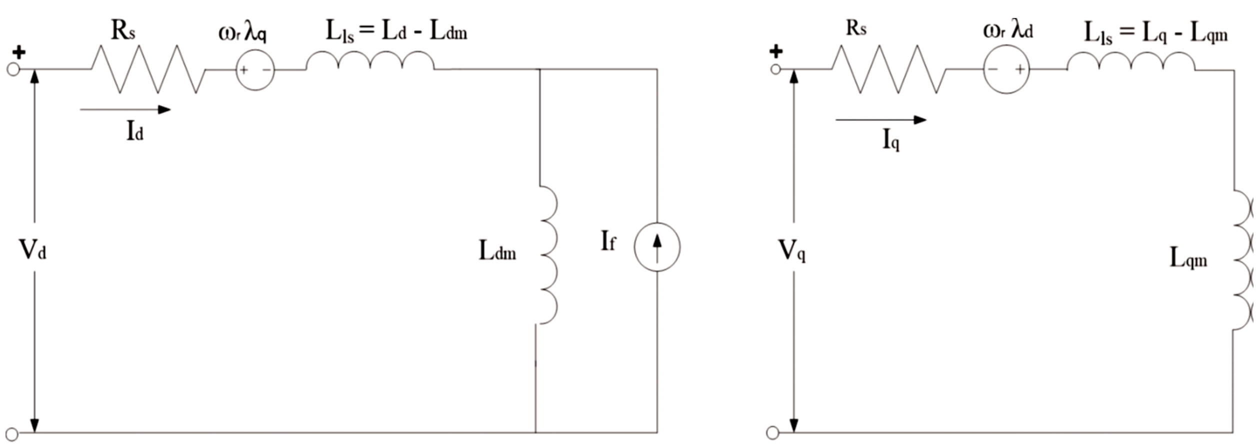

Figure 1: Permanent magnet synchronous machine circuit (motor)

The d and q-axis currents in the frequency (s) domain can be expressed as

$$\text{Id} = \frac{(-V_d - R_s I_d - \omega_r)}{sL_q} \text{ ---- (15)}$$

$$\text{Iq} = \frac{(-V_q - R_s I_q - \omega_r (L_d + L_{ls}) I_d + \omega_r \rho_r}{sL_q} \text{ ---- (16)}$$

CONCLUSION: Using Park's transformation, the electrical and mechanical equations of a permanent magnet synchronous machine is determined. These equations are their relations can be used for simulation using any digital signal processing software/simulation software. The electromagnetic output torque, mechanical speed and stator current are collectively dependent on the number of pole pairs, d-axis inductance, q-axis inductance, inertia, friction coefficient and flux (considering a motor). While the voltage, current and power outputs are dependent on the mechanical input torque (considering a generator).

REFERENCES:

Engineering solutions. (2020). No Title. Retrieved from https://en.engineering-solutions.ru/motorcontrol/pmsm/

Globe, C. (n.d.). No Title. Retrieved from https://circuitglobe.com/synchronous-machine.html

Hadziselimovic, M., & Stumberger, G. (2005). *Modeling of permanent magnet synchronous motor in d-q coordinates Modeling of Permanent Magnet Synchronous Motor in d-q Coordinates*. (January).

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