FUEL CELL FED HIGH BOOST CONVERTER POWERED PMSM DRIVE WITH ANN CONTROLLER -EV APPLICATIONS

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Abstract— *This paper presents a Fuel cell fed Permanent Magnet Synchronous Motor (PMSM). A high voltage boost converter with a smooth control scheme of a PMSM drive has been implemented using the developed simulation model. In the developed model, speed and torque as well as the voltages and currents of voltage source inverters components can be effectively monitored and analyzed. The developed simulation model has been implemented using Matlab and the dynamic response of PMSM drive has been analysed for constant varied speed. Also, the simulation results have been presented. The simulation results of the developed model have been validated with the circuit simulation using the PMSM block available in the Matlab/Simulink library. Therefore, it can be expected that the developed simulation model can be an easy to design tool for the design and development of PMSM drives for different control algorithms and topological variations with reduced computation time and memory size.*

Keywords— PMSM; ANN smooth control; Modelling; Fuel cell; High boost converter

1. INTRODUCTION

Earlier many DC drives were replaced by brushless AC drives. But now a day's PMSM has become the most used drive in machine tool servos and modern speed control applications. PMSM machine has high advantages like high efficiency, high power factor, high power density, easy maintenance, fast dynamic response In some cases due higher efficiency, high power density and high torque to inertia ratio PMSM replaces Induction motor (IM) and Synchronous motor (SM). Since PMSM rotor is made up of permanent magnet so there is no need of supplying magnetizing current through stator to produce air gap flux. DC excitation on the rotor, which is supplied by brushes and slip rings is required for SM which leads to rotor losses and requires regular maintenance. The variable speed and fast dynamic response drives in PMSM could be achieved by stator current control technique.

Since twenty years PMSM topic is quite interesting. One of the most common closed loop control technique used in a PMSM drive is Vector control technique. This Vector control techniques eliminates oscillating flux, torque responses in inverter fed induction motor and synchronous motor drives. This technique has different classification which includes as constant torque angle control, Unity power factor control, constant mutual air gap flux-linkages control, optimum-torque-per-ampere control and flux-weakening control. Mainly this depends on the type of application and the load characteristics.

An Appropriate control algorithm is necessary to perform a particular application for PMSM drive. To represent a complete drive system Incorporation of PMSM model along with the inverter model and load characteristics is essential. The simulation model for a complete PMSM drive is based on the mathematical model of an inverter fed PMSM is implemented using MATLAB\Simulink which can be used for stimulating algorithms. Speed, torque, voltages and currents of voltage source inverters are the components that can be effectively monitored and analyzed.

A. Boost Converter

2. PROPOSED CONVERTER TOPOLOGY AND OPERATION ANALYSIS:

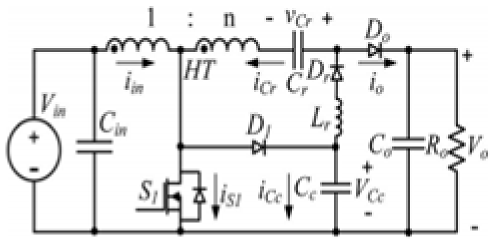

Fig.1 Proposed high step-up dc–dc converter with hybrid transformer

In this circuit diagram of the proposed converter.CTis the input capacitor; HT is the hybrid transformer with the turns ratio 1:n; S1 is the active MOSFET switch; D1 is the clamping diode, which provides a current path for the leakage inductance of the hybrid transformer when S1 is OFF, Cc captures the leakage energy from the hybrid transformer and transfers it to the resonant capacitor Cr by means of a resonant circuit composed of Cc , Cr , Lr , and Dr; Lr is a resonant inductor, which operates in the resonant mode; and Dr is a diode used to provide an unidirectional current flow path for the operation of the resonant portion of the circuit. Cr is a resonant capacitor, which operates in the hybrid mode by having a resonant charge and linear discharge. The turn-on ofDr is determined by the state of the active switch S1. Do is the output diode similar to the traditional coupled-inductor boost converter and Co is the output capacitor. Ro is the equivalent resistive load.

3. CLOSED LOOP SPEED CONTROL OF PMSM:

Vector Control scheme for closed loop PMSM drive shown in Fig. The constant torque method of vector control scheme has been considered for analysis. In this method, the angle between the rotor field and stator current phasor is known as torque angle and is maintained at 900 so that flux is kept constant, then the torque is controlled by the stator current magnitude [1]. The machine, speed and position feedback, speed and current controllers, and inverter constitute the PMSM drive. The error between the reference and actual speed has given as the input to the speed controller, which generates the torque reference and is proportional to Kiq.

Fuel cell mathematical equations
Nernst's equation output fuel cell dc voltage cross stack of the fuel cell at current I is given by the V_nernst=No(Eo+RT/2F{ln(p_H2p_O2)}
– Operating dc voltage (V), Eo – Standard reversible cell potential(V), Pi – Partial pressure of species i (Pa), - Number of cells in stack, R – Universal gas constant (J/ mol K), T – Stack temperature(K), F – Faraday's constant (C/mol),The main equations describing the slow dynamics of a SOFC can be written as follows.
dq_H2/dt = 1/t_r [-q_H2 + 2K_r/U opt Idc] dp_H2/dt = 1/t_H2 [-p_H2 + 1/K_H2 (q_H2-2K_r Idc] dp_O2/dt = 1/t_O2 (-p_O2 + 1/K_O2 (1/r_H0 q_H2 - K_rIdc)]
dp_H2o /dt = 1/ t_H20 (-p_H20 + 2K_r Idc/K_H20)
q_H2 – Fuel flow (mol/s)q_O2 – Oxygen flow (mol/s),K_H2 – Valve molar constant for hydrogen (kmol/s atm),K_O2 – Valve molar constant for oxygen (kmol/s atm),
K_H2O – Valve molar constant for water (kmol/s atm),
ô_H2 – Response time for hydrogen (s),
ô_ O2 – Response time for oxygen (s),
ô_H2O – Response time for water (s),
ô_f – Fuel response time (s),
Uopt – Optimum fuel utilization,
r_HO – Ratio of hydrogen to oxygen,
K_r – Constant (kmol/s A).

4. MATHEMATICAL MODEL OF PMSM:

The Mathematical model of PMSM existing is represented in the following .The stator of the PMSM and the wound rotor synchronous motor are similar. The permanent magnets used in the PMSM are of a modern rare-earth variety with high resistivity, so induced currents in rotor are negligible. In addition, there is no difference between the back EMF produced by a permanent magnet and that produced by an excited coil. Hence the mathematical model of a PMSM is similar to that of the wound rotor SM. The rotor reference frame is chosen because the position of the rotor magnets determines the instantaneous induced emfs and subsequently the stator currents and torque of the machine independently of the stator voltages and currents. The following assumptions are considered in the derivation.

- Saturation and parameter changes are neglected
- Stator windings are balanced with the induced EMF is sinusoidal
- Eddy current and hysteresis losses are negligible
- There are no field current dynamics
- There is no cage on the rotor

The equivalent circuits of PMSM in d, q axes in rotor reference frame are shown in fig 1 and fig 2 respectively.

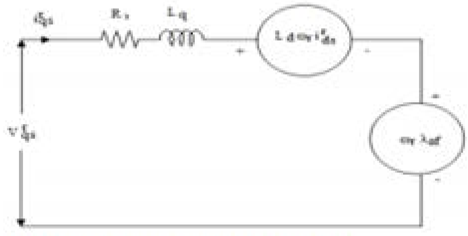

Fig. 1.Stator q-axis equivalent circuit

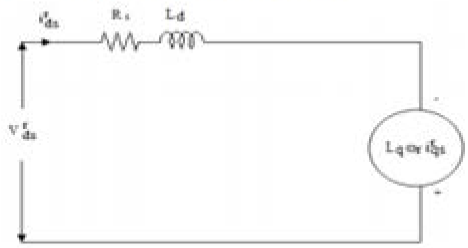

Fig. 2.Stator d-axis equivalent circuit

With these assumptions, the stator voltage d-q equations of the PMSM in the rotor reference frame are given by equations (1) and (2).

$$V_{qs} = R_s i_{qs} + p\lambda_{qs} + \omega \lambda_{ds} \quad (1)$$

$$V^r_{ds} = R_s i^r_{ds} + p\lambda^r_{ds} - \omega \lambda^r_{qs} \quad (2)$$

The stator flux linkages is given by equations (3) to(5)

$$\lambda^r_{qs} = L_q i^r_{qs} \quad (3)$$

$$\lambda^r_{ds} = L_d i^r_{ds} + L_m i_{fr} \quad (4)$$

$$L_m i_{fr} = \lambda_{af} \quad (5)$$

Vrqs and Vrds are the d,q axes voltages,irqs and irds are the d, q axes stator currents in rotor reference frame, LdandLq are the d, q axis inductances and λd and λq are the d, q axis stator flux linkages in rotor reference frame, while Rs and ωrare the stator resistance andinverterfrequency, respectively. λafis the flux linkage due to the rotormagnetslinkingthestator.

Equations (6) and (7) is obtained by substitutingequations (3) to (5) in (1) and(2)

$$V^r_{qs}=R_s i^r_{qs}+p(L_q i^r_{qs})+\omega_r(L_d i^r_{ds}+\lambda_{af}) \quad (6)$$

$$V_{ds}\text{-}R_s i^r_{ds}+P(L_d i^r_{ds})-\omega r(L_q i^r_{qs}) \quad (7)$$

Equations (8) and (9) is obtained by rearranging equations (6) and (7) in matrixform

$$\begin{bmatrix} Vrqs \\ vrds \end{bmatrix}=\begin{bmatrix} Rs+pLq & \omega rLd \\ -\omega rLq & Rs+pLd \end{bmatrix}\begin{bmatrix} irqs \\ irds \end{bmatrix}+\begin{bmatrix} \omega r\lambda af \\ 0 \end{bmatrix} \quad (8)$$

The electromagnetic torque developed by the motor is given by equation (9)

$$T=\frac{3}{2}\frac{P}{2}\{\lambda^r_{ds}i^r_{qs}-\lambda^r_{qs}i_{rds}\} \quad (9)$$

The three phase stator voltage equations is given by equations (10) to (12)

$$V_{as}=V_m \sin\omega t \quad (10)$$

$$V_{bs}=V_m \sin(\omega t-2\pi/3) \quad (11)$$

$$V_{cs}=V_m \sin(\omega t-2\pi/3) \quad (12)$$

V as ,Vbs,Vcsare a-phase, b-phase and c-phase stator voltages respectively. Vm is the peak value of the stator voltage. ω is the synchronous speed in rad/sec. The stator voltages in the 'abc' axes Vabcis transferred to the d, q axes Vqd0 by using park's transformation.

$$V_{qdos}=K_s V_{abcs} \quad (13)$$

The transformation matrix Ks is given by equation(14)

$$K_s=\frac{2}{3}\begin{bmatrix} cos\theta & cos\left(\theta-\frac{2\pi}{3}\right) & cos(\theta+2\pi/3) \\ sin\theta & sin\left(\theta-\frac{2\pi}{3}\right) & sin(\theta+2\pi/3) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (14)$$

$$\begin{bmatrix} vqs \\ vds \\ vos \end{bmatrix}=\frac{2}{3}\begin{bmatrix} cos\theta & cos(\theta-\frac{2\pi}{3}) & cos(\theta+\frac{2\pi}{3}) \\ sin\theta & sin(\theta-\frac{2\pi}{3}) & sin(\theta+\frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} vas \\ vbs \\ vcs \end{bmatrix} \quad (15)$$

θ is the rotor angle. Transformation of variables from stationary to synchronously rotating reference frame are given by equations (16) and (17)

$$V^e_{qs}=V_{qs}\cos\theta_c+V_{ds}\sin\theta_c \quad (16)$$

$$V^e_{ds}=V_{ds}\cos\theta_e-V_{qs}\sin\theta_e \quad (17)$$

The stator current equations in synchronously rotating reference frame are given by equations (18) and (19).

$$i^e_{qs}=\int \overline{Lq} - \omega e\frac{\lambda af}{Lq}-\frac{Rs}{Lq}i^e_{qs}-\omega e\, i^e_{ds}\overline{Lq} \quad (18)$$

$$i^e_{ds}=\int \overline{Ld} - \overline{Lq}i^e_{ds}-\omega e\, i^e_{qs}\overline{Ld} \quad (19)$$

Veqs,Vedsandieqs,ieds are q-axis and d-axis voltage and current in synchronously rotating reference frame respectively.

The expression for electromagnetic torque developed by the motor in terms of inductances and current are given by equation (20) as

$$T=3/2\ P/2\ \{\lambda_{af}i^e_{qs}+(L_d-L_q)i^e_{qs}i^e_{ds}\} \quad (20)$$

This equation relating the load torque and the electromagnetic torque is given by the equation (21)

$$T_e=T_L+B\omega_m+J\ (d\omega m/dt) \quad (21)$$

P is the number of pole pairs,TL is the torque is damped coefficient,ωm is the rotor speed, and J is moment of inertia.

Rotor mechanical speed is given by equation (22)

$$\omega m=T\int Te-Tl-B\omega m \quad (22)$$

Rotor electrical Speed ωeis given by equation

$$\omega_e=P/2\,\omega_m \quad (23)$$

Rotor angle θm is given by equation (24)

$$\theta_m=\int\omega_m \quad (24)$$

angle between the rotor field and the stator current phasor is known as torque angle and is maintained at 90 0 so flux is kept constant, then the torque is controlled by the stator current magnitude(1). The machine, speed and position feedback, speed and current controllers and inverter constitute the PMSM drive. The error between the reference and actual speed has given as the input to the speed controller, which generates the torque reference and is proportional to ktiq.

The equation (20) by substituting id=0, equation (25) and (26) is obtained.

$$T=K_t i^e_{qs} \quad (25)$$

$$K_t=\frac{3}{2}\frac{P}{2}\lambda_{af} \quad (26)$$

The stator current idqo in dq-axis is transformed to 'abc' axis by inverse Parks Transformation given by equation

$$i_{abcs}=k^{-1}{}_s i_{qd0s} \quad (27)$$

$$K^{-1}{}_s=\frac{2}{3}\begin{bmatrix} cos\theta & sin\theta & 1/2 \\ \cos\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta-\frac{2\pi}{3}\right) & 1/2 \\ \cos\left(\theta+\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) & 1/2 \end{bmatrix} \quad (28)$$

The reference current ias,ibs and ics are generated by substituting equation (28) in equation (27).

In the constant air gap flux mode of operation.kt is constant upto base speed and is equal to unity. Hence, the torque reference is directly proportional to iq, which is transformed to 'abc' axes by using inverse park's transformation given by equation (27). The 'dq0 to abc' transformation block shown in fig gives the stator reference current ia,ib and icin'abc' axes which is compared with the actual current and the current error is given to a hysteresis controller. The hysteresis current controller generates triggering pulses to the inverter in such a way that the actual current follows the reference current.

5. Block Diagram

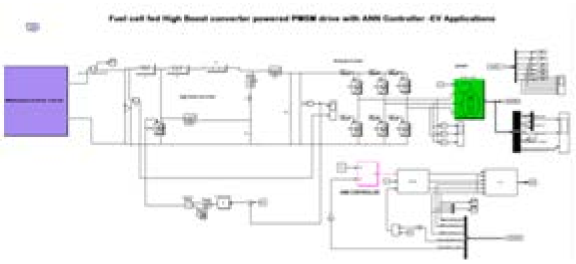

Fig.3. Fuel cell High boost dc dc converter with PMSM with Ann Control.

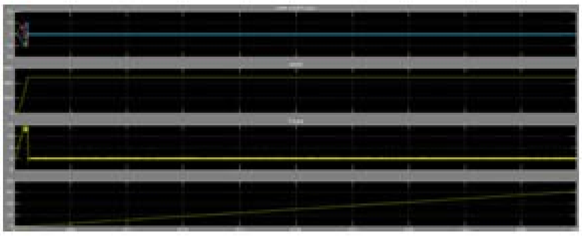

Fig.4. Response of FC fed PMSM AnnControl

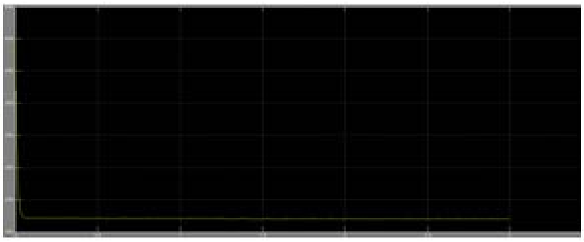

Fig 5.Voltage of fuel cell

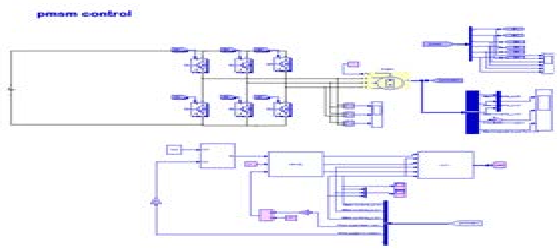

Fig.6.simulation model for fuzzy control

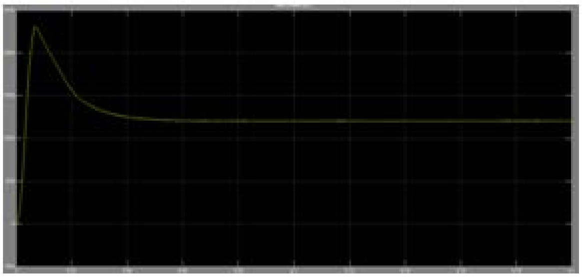

Fig.7. Response of PMSM speed for fuzzy control

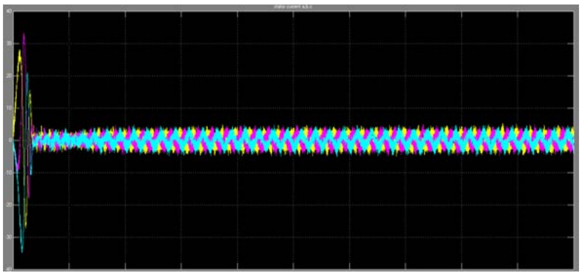

Fig 8. Three phase current with fuzzy controller

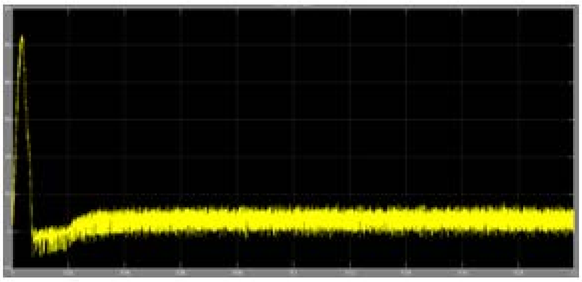

Fig 9. Torque when fuzzy controller adopted

6. Conclusion:

An advanced simulation model of closed loop PMSM drive system has been developed by utilizing the fuel cell fed PMSM with ANN controller and three phase VSI inverter. The developed system simulation model has been validated by circuit simulation model of the same scheme which shows the accuracy of the developed model. This developed model can be well utilized in the design and development of closed loop PMSM drives system for experimenting with different control algorithms and topological variations but with a much reduced computational time and memory size and it is better option when compared to fuzzy control.It is useful in green energy applications.

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