The Analysis and Design of a Zoning Control System for New Hybrid Excitation Synchronous Machine

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Abstract

The new hybrid excitation synchronous machine (HESM) has been widely applied in different fields. This kind of motor is characterized by distinct wide speed regulation. The design of HESM integrates the advantages of permanent magnet motor and electro-magnetic motor. In actual applications, a new type of speed control mode can be produced. Such a control mode is called zoning control. On this basis, in this paper, a zoning control system for HESM is analyzed and the design idea is explored.

Keywords

New Hybrid Excitation Synchronous Machine; Zoning Control System; Analysis; Design.

1. Introduction

New hybrid excitation synchronous machine (HESM) is characterized by high efficiency and large torque/mass ratio. It is more convenient in actual magnetic field regulation. Based on the characteristics of HESM, it is of significant value in the field of engineering application, and so on. In this paper, to investigate the operation and design of a zoning control system for HESM, a zoning control model is established. By regulating armature current and exciting current reasonably, the speed of motor can be switched, i.e., high, medium and low.

2. The Structure and System Design of HESM

The structure of the proposed HESM in this paper was synchronous. The actual structure of this motor is shown in Figure 1 below. From this figure, it can be observed that an armature winding was set on the outer stator of motor and an exciting winding was set on the inner stator. In the claw pole of motor structure, different types of magnetic fluxes needed to share magnetic force in parallel. In the magnetic circuit of claw pole, exciting flux and permanent flux needed to be connected in parallel. To guarantee that the motor wouldn't face the risk of permanent demagnetization in actual operation, the reluctance of magnetic steel must be led into the air gap through iron core. In doing so, whether we implemented field weakening or field strengthening on the motor to regulate speed, the above problems wouldn't exist [1].

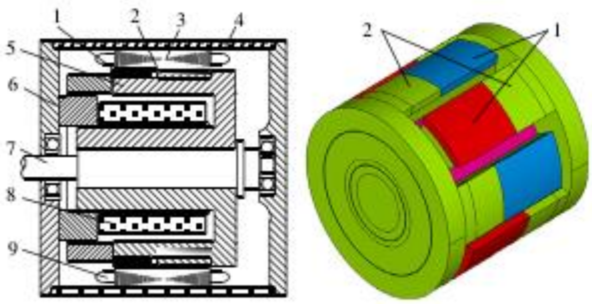


Figure 1. The Structure and Rotor Model of HESM

Table 1. The Structure of HESM

Position	1	2	3	4	5
Name	Permanent Magnet	Iron Pole	Stator Core	Outer Casing	Claw Pole
Position	6	7	8	9	
Name	End Cap	Shaft	Exciting Winding	Armature Winding	

With the aid of vector control principle, in the d-q coordinate system, we created a HESM control system model. By comparing actual function modules, we found that there were differences between HESM and PMSM (permanent magnet synchronous motor). Among them, the function modules of HESM are shown in Table 2 below. The function modules of PMSM are shown in Table 3 below.

Table 2. Function Models of HESM

Function Model	Transformation Model	Control Model	Modulation Model	Drive Model
Name	HESM, Clarke transformation, Park and Inverse Park transformation	Speed control, current distributor, d-axis control, q-axis current control	Space vector pulse width modulation, exciting current pulse width modulation	Armature drive, exciting drive

Table 3. Function Models of PMSM

Function Model	Transformation Model	Control Model	Modulation Model	Drive Model
Name	HESM, Clarke transformation, Park and Inverse Park transformation	Speed control, d-axis control, q-axis current control	Space vector pulse width modulation	Armature drive

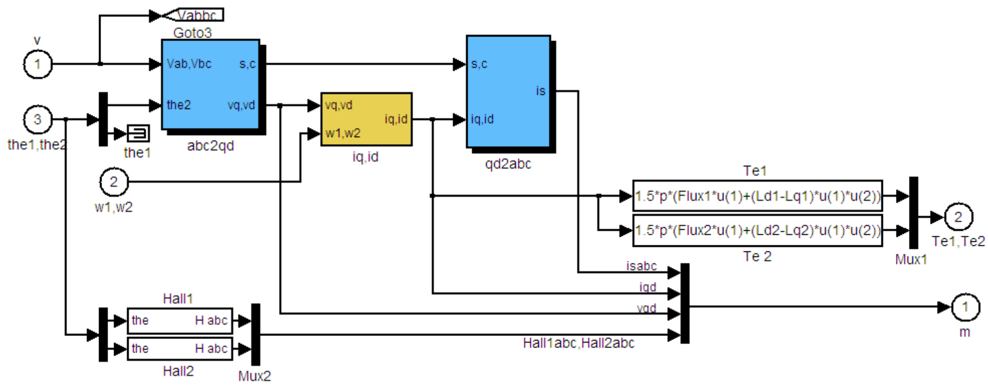


Fig. 2 Electrical model

Through a comparative analysis of the above two tables, the function models of HESM and PMSM were roughly the same. But compared with HESM, the function models of PMSM didn't include current distributor, exciting current pulse width modulation or exciting drive [2].

3. The Zoning Control Modes of HESM

There were three types of zoning control modes for HESM, i.e., low-speed control, medium-speed control and high-speed control. By studying the characteristics of HESM, we found that compared with other exciting current control modes, HESM had distinct features. For example, HESM can only carry out positive exciting current control and didn't need to consider negative exciting current.

$$\left.\begin{aligned} B &= \nabla \times A \\ E &= V \times (\nabla A) - \partial A / \partial t \end{aligned}\right\} \quad (1)$$

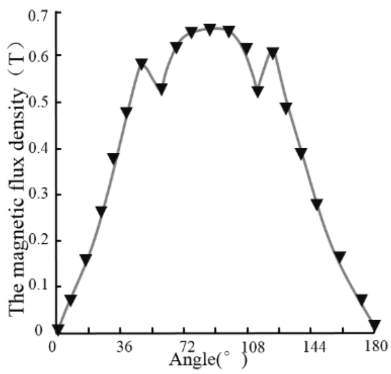
In this paper, the problems and the amount which need to be solved are under the stationary two-dimensional cylindrical coordinate system [22], and we need to neglect the end effect as well. Therefore, the rotational speed V only has the tangential component ($V = \{0, r\Omega, 0\}$, Ω is mechanical angular velocity), the magnetic vector potential A ($A = \{0, 0, A\}$, the current density T $T = \{0, 0, J\}$), the electric field strength E $E = \{0, 0, E\}$, it only has an axial component, Magnetic induction intensity B ($B = \{B_r, B_\varphi, 0\}$), Magnetic field intensity H ($H = \{H_r, H_\varphi, 0\}$), and the magnetization M ($M = \{M_r, M_\varphi, 0\}$), it only has a radial and tangential component. From formula (1), (2) and (3), we can deduce the diffusion equation expressed by the magnetic vector potential A, and it was shown in the following formula:

$$\nabla^2 \times A = \mu\sigma \frac{\partial A}{\partial t} - \mu\sigma V \times (\nabla \times A) - \mu_0 \times (\nabla \times M) \quad (2)$$

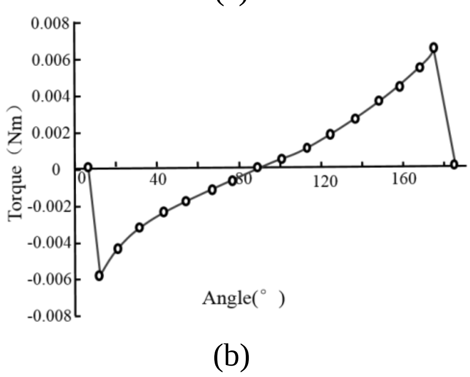
Since the equality on both sides of the vector in formula (4) are axial, thus, the vector sum can be written as the formula (5), and its algebra is:

$$\begin{aligned} &\frac{\partial^2 A}{\partial t^2} + \frac{1}{r}\frac{\partial A}{\partial t} + \frac{1}{r^2}\frac{\partial^2 A}{\partial \varphi^2} = \mu\sigma \frac{\partial A}{\partial t} + \\ &\mu\sigma\omega_r \frac{\partial A}{\partial \varphi} + \mu_0 \left(\frac{1}{r}\frac{\partial M_r}{\partial \varphi} - \frac{1}{r} M_\varphi \right) \end{aligned} \quad (3)$$

When the exciting current in the rotor's magnetic shunt was turned to zero, the motor would be converted to the state of PMSM, that is, the field-weakening state mentioned in this study. When the HESM in the rotor's magnetic shunt was in a low-speed area, the rotation speed n<n1. At such a speed, the exciting current reached a maximum. The dynamic performance of motor was high [3].



(a)



(b)

Fig.3 (a) Flux density waveform when parallel magnetization; (b) Motor cogging torque waveforms;

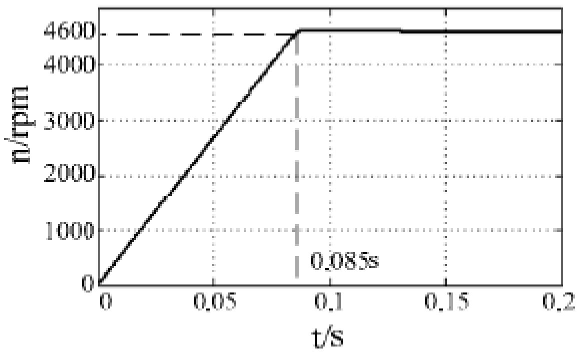


Fig.4 Simulation of load torque of 0N

3.1 Low-speed control

When the motor was in a low-speed control mode, the exciting current remained the maximum, so as to enhance magnetic effect during the operation of motor using the maximum exciting current. Meanwhile, when the motor ran at a low speed, the actual counter EMF was low and would not be affected by voltage limit circle. Under the control of id=0, an electromagnetic torque equation was determined. When there was no exciting current during the operation of motor system, the reference torque current output by the speed controller was the torque component of armature current. Here, we may consider that the efficiency of HESM was consistent with that of PMSM. The following formula was obtained:

$$\mathrm{T_e} = \frac{3}{2}P(\psi_{pm} + M_{sf} i_{fref}) i_{qref} = \frac{3}{2}P\psi_{pm} i_{Tref} \tag{4}$$

Table 4. The Reference Value of Electromagnetic Torque

Symbol	P	ψ_{pm}	M_{sf}	i_{fref}
Name	Number of pole pairs	Flux linkage of permanent magnet	Mutual inductance between armature winding and exciting winding	Reference value of exciting current

3.2 Medium-speed control

In the zoning control of HESM, medium-speed control exhibited high reliance on *nBdec*. In the vector control of HESM, if the currents of *id* and *if* were supposed to be the same, then we can identify that *nr* and *Eq* had a linear relationship. Based on the maximum speed of HESM, n maintained a linear relationship with DC bus [4]. The resulting linear fitting was:

$$n_{\max} = K\mathrm{vU}_{dc} + N_0$$

$$n_{Bdec} = K_b n_{\max}$$

Table 5. Introduction to Parameters

Kv	N0	Kb
Limit speed/voltage ratio	N0 was an offset value when <13	Kb was a field-weakening base speed coefficient, whose range was (0.8-0.95)

3.3 High-speed control

In the control of high-speed area, the area was divided into Zone 1 and Zone 2 for control. The speed was regulated by adjusting the current of d-axis. When the motor speed reached $\mathrm{nB_{dec}}$, we adopted the control mode of constant q-axis component. The characteristic parameters of HESM prototype are shown as follows:

Table 6. Part of the Characteristic Parameters of HESM

Name	Parameter	Value
	PN/W	600
	Tn/(N.m)	9
	IN+/A	5
	P	4

4. Conclusion

To sum up, in this paper, we carry out an in-depth study into the structure and control modes of a zoning control system for HESM. There are three types of zoning control modes for HESM, i.e., low-speed control, medium-speed control and high-speed control. In actual research, it is found that HESM can only carry out positive exciting current control and doesn't need to consider negative exciting current. When the exciting current in the rotor's magnetic shunt is turned to zero, the motor will be converted to the state of PMSM.

References

[1] Huang M, Lin H, Jin P, et al. Design and analysis on stage control systems for a novel hybrid excitation synchronous motor [J]. Zhongguo Dianji Gongcheng Xuebao/proceedings of the Chinese Society of Electrical Engineering, 2012, 32(12):120-125.

[2] Yang C F, Lin H Y, Liu X P. Control strategy and simulation for hybrid excitation synchronous machine [J]. Dianji Yu Kongzhi Xuebao/electric Machines & Control, 2008, 12(1):27-33.

[3] Amara Y, Hoang E, Gabsi M, et al. Measured Performances of a New Hybrid Excitation Synchronous Machine [J]. Epe Journal, 2002, 12(4):42-50.

[4] Zhen G, Tian Y, Fu X. The Design and the Control Principle Analysis of a New Hybrid Excitation Synchronous Generator [C]// International Conference on Industrial Control and Electronics Engineering. 2012:1914-1916.