DESIGN OF PERMANENT MAGNETS TO GUARANTEE FREQUENCY-CHANGING STARTUP FOR PM SYNCHRONOUS MACHINES

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Purpose

The permanent-magnet synchronous machine (PMSM) is becoming more and more attractive for both industrial and electric vehicle applications [1] because of its inherent advantages of high power density and high efficiency. However, the PMSM is not self-starting. Apart from inserting additional cage windings in the rotor, the most common starting method is to gradually increase the applied frequency by using a frequency-changing inverter [2]. Nevertheless, due to the nonlinear dynamics of the PMSM, this frequency-changing startup may be failure or exhibit chaotic behaviors. In this paper, the nonlinear relationship between the sizing of PMs and the startup behaviors of PMSMs will be investigated. Both computer simulation and experimental results will be given to support the design criterion.

Startup and Chaos

A 3-phase inverter-fed PMSM is modeled in the d-q frame as given by (1). By applying bifurcation analysis to (1), it can be deduced that the PM flux exhibits an important effect on the startup behavior. Namely, the frequency-changing startup is successful only when the PM flux is lower than a critical value; otherwise, chaos may occur. This finding illustrates that the sizing of PMs is crucial to avoid chaos during the frequency-changing startup of PMSMs.

$$\begin{cases} L_{ds}\dfrac{di_{ds}}{dt} = -V\sin(2\pi ft-\theta+\alpha) - R_s i_{ds} + n_p\omega_r L_{qs} i_{qs} \\ L_{qs}\dfrac{di_{qs}}{dt} = -V\cos(2\pi ft-\theta+\alpha) - R_s i_{qs} - n_p\omega_r L_{ds} i_{ds} + n_p\psi_{pm}\omega_r \\ J\dfrac{d\omega_r}{dt} = \dfrac{3}{2}n_p(L_{ds}-L_{qs})i_{ds}i_{qs} - \dfrac{3}{2}n_p\psi_{pm}i_{qs} - B_m\omega_r + T_m \\ \dfrac{d\theta}{dt} = n_p\omega_r \end{cases} \tag{1}$$

Simulation and Experimentation

Based on a practical 3-phase PMSM, bifurcation diagrams of the rotor speed with respect to the applied frequency and PM flux are simulated in Figs. 1 and 2, respectively. They illustrate that the frequency-changing startup will result in chaos if the PMs are not properly sized, namely when the PM flux which equals 0.1472 Wb is larger than the critical value of 0.0914 Wb. Fig. 3 shows the measured chaotic waveforms of d-axis current, q-axis current and rotor speed as well as their phase-plane trajectories. It can be found that the waveforms exhibit a well-known property of chaos (namely, random-like but bounded), while the trajectories resemble the Rössler attractors. Detailed derivation, simulation and experimental results will be included in the full paper.

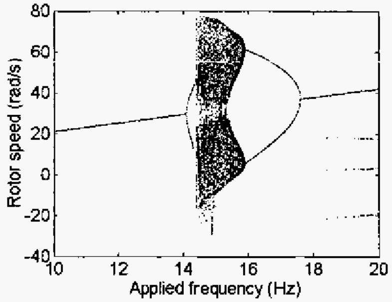

Fig. 1. Rotor speed bifurcation diagram with respect to applied frequency.

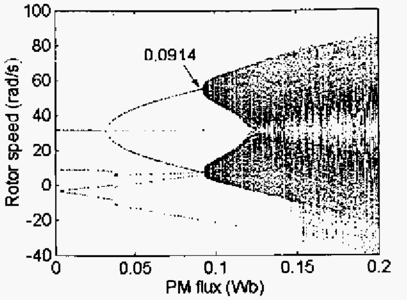

Fig. 2. Rotor speed bifurcation diagram with respect to PM flux.

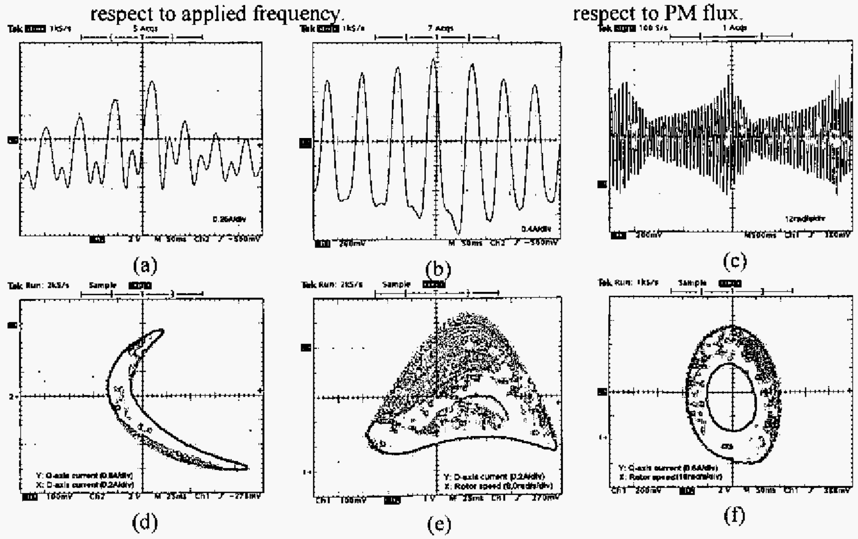

Fig. 3. Measured chaotic waveforms and trajectories at failure startup.

References

[1] J. Gan, K.T. Chau, C.C. Chan and J.Z. Jiang, "A new surface-inset, permanent-magnet, brushless DC motor drive for electric vehicles," *IEEE Transactions on Magnetics*, Vol. 36, 2000, pp. 3810-3818.

[2] J.F. Gieras and M. Wing, *Permanent Magnet Motor Technology: Design and Applications*. New York: Marcel Dekker, 2002.