The Relationship of Magnetomotive Force under Different Excitation Modes of Dual-excited Synchronous Generator

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Based on the traditional synchronous generator, a dual-excited synchronous generator with two sets of symmetrical field windings on the rotor is designed. Firstly, the relationship of the fundamental and harmonic magnetomotive force is deduced between the single-axis and dual-axis excitation of the dual-excited generator. The correctness of the theoretical derivation is verified by the finite element simulation. Then, the air gap flux density in different rotor pitch is calculated and compared with the traditional synchronous generator. Finally, the results show that the air gap flux density waveform is better when the rotor pitch is 20. The fundamental component of the air gap flux density in single-axis excitation is smaller than that of the traditional generator; while the fundamental component of the air gap flux density in dual-axis excitation is greater than that of the traditional generator. The 3td harmonic component of the air-gap flux density is larger than that of traditional generator; while the 5th and 7th harmonic component of the air-gap flux density is smaller than that of traditional generator.

***Index Terms*—Dual-excited synchronous generator; Different excitation mode; Magnetomotive force, Air-gap flux density**

I. Introduction

The high stability of the dual-excited synchronous generator can supply high-reliability power for key users and special important places. It also can provide power for incident follow-up treatment in the event of a large area of power outages [1]. The advantages of dual-excited synchronous generator are that the magnitude and direction of excitation magnetomotive force can be changed because of its two sets of field windings in the rotor [2-3]. Therefore, it is necessary to study the amplitude and waveform of excitation magnetomotive force for designing and manufacturing dual-excited synchronous generator.

In order to study the characteristic of dual-excited generator, this paper designs a dual-excited synchronous generator with two sets of field windings based on the structure of traditional turbine generator. Then, the relationship of the fundamental and harmonic magnetomotive force is deduced between the single-axis excitation and the dual-axis excitation of the dual-excited synchronous generator. The correctness of the theoretical derivation is verified by the finite element simulation. Finally, the air gap flux density of different rotor pitch is calculated, and the results are compared with that of the traditional synchronous generator. The results provide theoretical basis for the design and manufacture of the dual-excited generator.

II. The Relationship of Excitation Magnetomotive Force under Different Excitation Modes

A. The rotor winding structure of dual-excited generator

In this paper, a dual-excited generator with two sets of field windings is designed on the basis of the traditional two-pole synchronous generator. Fig.1 is the rotor structure of dual-excited generator. The number of rotor slot is 48. In Fig.1, the red zone and green zone are the field windings in d-axis and q-axis; the blue zone is rotor slot wedges.

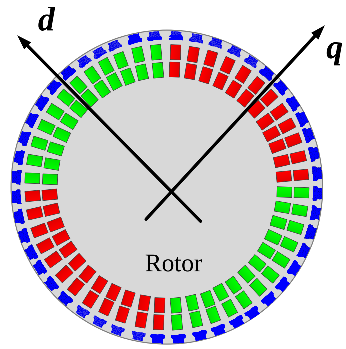

Fig.1 the rotor structure of dual-axis excited generator with full-pitch

B. The relationship of magnetomotive force in different excitation modes

The fundamental and harmonic magnetomotive force of d-axis field winding is represented by F^1_{fd}, F^3_{fd}, F^5_{fd}, F^7_{fd}; the fundamental and harmonic magnetomotive force of q-axis field winding is represented by F^1_{fq}, F^3_{fq}, F^5_{fq}, F^7_{fq}. When the saturation effect is neglectd, these magnetomotive forces produce the air-gap flux density respectively. Take fundamental magnetomotive force as an example, the fundamental magnetomotive force $F^1_{single\text{-}axis}$ (F^1_{fd}) produce fundamental flux density $B^1_{single\text{-}axis}$ (B^1_{fd}) under single-axis excitation; The d, q-axis fundamental magnetomotive force F_{fd} and F_{fq} produce fundamental flux density B_{fd} and B_{fq} respectively. The relationship of magnetomotive force under two excitation modes are shown in Fig.2.

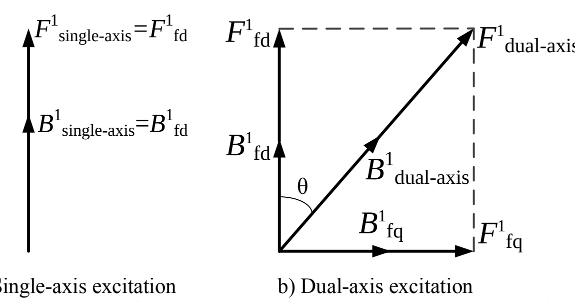

Fig.2 The relationship of magnetomotive force under two excitation modes

The space vector of 1, 3, 5, 7th magnetomotive force of d, q axis of can be expressed as:

$$\begin{cases}\dot{F}_{fd}^{1}=F_{fd}^{1}\angle 90^\circ\\ \dot{F}_{fq}^{1}=F_{fq}^{1}\angle 0^\circ\end{cases}\quad \begin{cases}\dot{F}_{fd}^{3}=F_{fd}^{3}\angle 270^\circ=F_{fd}^{3}\angle\text{-}90^\circ\\ \dot{F}_{fq}^{3}=F_{fq}^{3}\angle 0^\circ\end{cases}$$
$$\begin{cases}\dot{F}_{fd}^{5}=F_{fd}^{5}\angle 450^\circ=F_{fd}^{5}\angle 90^\circ\\ \dot{F}_{fq}^{5}=F_{fq}^{5}\angle 0^\circ\end{cases}\quad \begin{cases}\dot{F}_{fd}^{7}=F_{fd}^{7}\angle 630^\circ=F_{fd}^{7}\angle\text{-}90^\circ\\ \dot{F}_{fq}^{7}=F_{fq}^{7}\angle 0^\circ\end{cases} \tag{1}$$

When the same current is applied to the d and q axis excitation windings, there are the following relations:

$$\begin{cases}F_{\text{dual-axis}}^{1}=\sqrt{2}F_{\text{single-axis}}^{1}\\ F_{\text{dual-axis}}^{3}=\sqrt{2}F_{\text{single-axis}}^{3}\\ F_{\text{dual-axis}}^{5}=\sqrt{2}F_{\text{single-axis}}^{5}\\ F_{\text{dual-axis}}^{7}=\sqrt{2}F_{\text{single-axis}}^{7}\end{cases} \tag{2}$$

III. Finite Element Simulation of Dual-Excited Generator

A. The influence of different pitch on the air-gap flux density

When the saturation is neglected, the relationship of magnetomotive force under different excitation modes can be reflect by the air-gap flux density. Therefore, the finite element model was used to calculate the air-gap flux density under different excitation modes. When the pitch of field winding (y_1) is 24, the air-gap flux density under different excitation modes are shown in Fig.3. Table I shows the harmonic component of air-gap flux density under different pitch of field winding.

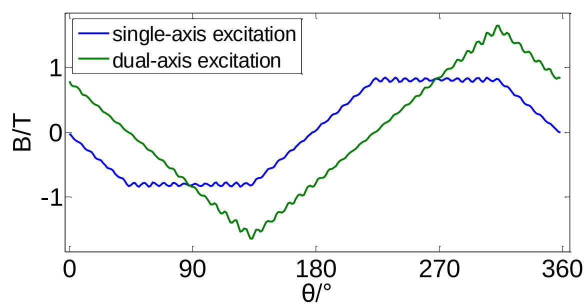

Fig.3 The comparison of gap flux density under single-axis excitation and dual-axis excitation

Table I Harmonic component of air-gap flux density

y_1	-	B_1	B_3	B_5	B_7
24	single-axis	0.9271	0.1029	0.0361	0.0195
	dual-axis	1.3112	0.1455	0.0511	0.0276
20	single-axis	0.8957	0.0735	0.0095	0.0058
	dual-axis	1.2668	0.1040	0.0135	0.0082
16	single-axis	0.8031	0.0015	0.0332	0.0167
	dual-axis	1.1358	0.0021	0.0470	0.0236

From Fig.3 and Table I, we obtained some results as follow:

1) The relationship of air-gap flux density under different excitation modes meets equation (2).

2) When the rotor winding is full pitch, the magnitudes of the 3, 5 and 7th harmonic flux densities are large; when the pitch is 16, the amplitude of the 3rd harmonic flux density is small; when the pitch is 20, the amplitude of the 5th and 7th harmonic magnetic flux density is small.

B. Comparison of air-gap flux density between traditional synchronous generator and dual-excited generator

When the pitch of field winding is 20, the air-gap flux density waveform is close to the sine wave and the fundamental amplitude is not weaken too much. In order to analysis the fundamental and harmonic component, the air-gap flux density of dual-excited generator are compared with that of traditional synchronous generator. The results are shown in Fig.4. The values of harmonic component are shown in Table II. The magnitude of the gap flux density is smaller than that of the traditional synchronous generator, while the amplitude of the flux density is larger than that of the traditional synchronous generator. The 3th harmonic the air-gap flux density is larger than that of traditional synchronous generator, while the air-gap flux density of 5th and 7th harmonic is smaller than that of traditional synchronous generator.

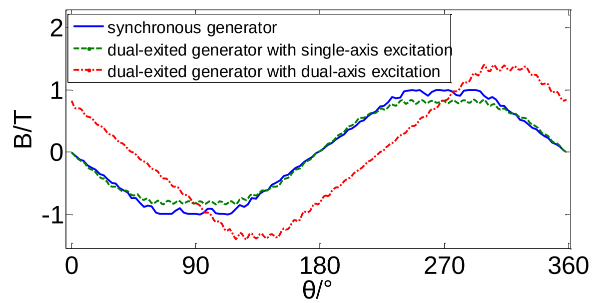

Fig.4 The comparison of gap flux density under single-axis and dual-axis excitation

Table II Harmonic analysis of air gap flux density

y_1	-	B_1	B_3	B_5	B_7
-	Synchronous generator	1.0131	0.0063	0.0368	0.0203
20	single-axis	0.8957	0.0735	0.0095	0.0058
	dual-axis	1.2668	0.1040	0.0135	0.0082

IV. Conclusions

1. The relationship of fundamental and harmonic magnetomotive between single-axis and dual-axis excitation is obtained. The correctness of relationship is verified by finite element simulation.

2. When the pitch of field winding is 20, the air-gap flux density waveform is close to the sine wave and the fundamental amplitude is not weakening too much. The magnitude of the gap flux density is smaller than that of the traditional synchronous generator, while the amplitude of the flux density is larger than that of the traditional synchronous generator.

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