Simulation of Synchronous Generator's Dynamic Operation Characteristics

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Abstract: *According to the relationship between electromagnetic synchronous generator and the synchronous dynamic operation characteristics of the generator, a mathematical model, by which the electromagnetic variation can be clearly described, is built. A simulation study on the operation characteristics of synchronous generator dynamic is done. This work provides a theoretical basis for optimal design of the synchronous generator.*
Keywords: *synchronous generator, dynamic operation, mathematical model, simulation*

I. INTRODUCTION

The dynamic operation process of the synchronous generator is a common fault running, such as the outlet end short-circuit of the armature, Starting from the moment of short circuit, the generator is in a sudden short-circuit transition process, generally the moment of the impact of short-circuit current is large (the maximum instantaneous value can be 10-20 times of the rated current), so large electromagnetic force and electromagnetic torque in the generator are generated (brake torque and alternating torque), which cause great damage to the mechanical structure of the generator, while this process is determined by the parameters of the generator, so study on the dynamic operating characteristics of the generator has a very important significance for the motor optimization design.

II.STRUCTURE OF SALIENT POLE SYNCHRONOUS GENERATOR

Salient pole synchronous generator has a general structure and properties of the generator, and the conclusion of which is readily extended to non-salient pole generator, in this paper, salient pole synchronous generator is used for the study. Figure 1 shows the simplified structure of salient pole synchronous generator, with three armature windings, a field winding and two damper windings, abc and dq0 coordinate system is marked in the figure, the generator in the positive direction of the voltage and current is: the generator stator winding is obeyed according to usual practice, the negative flux is generated by the forward current, while the rotor winding also follows the practice, the forward current produces a positive flux. The positive flux is generated by the forward current.

During the running of the generator, the internal magnetic field distribution and variation of EMF quite are very complex, especially in the dynamic process, the following assumptions is made in this paper: symmetrical distribution of the three-phase stator windings; ignoring the loss of hysteresis and eddy current; Excluding the impact of magnetic saturation; all winding resistances are constant; the speed of the generator remaining unchanged during the process; the damper winding is instead by a horizontal axis damper winding, and a vertical axis damper winding.

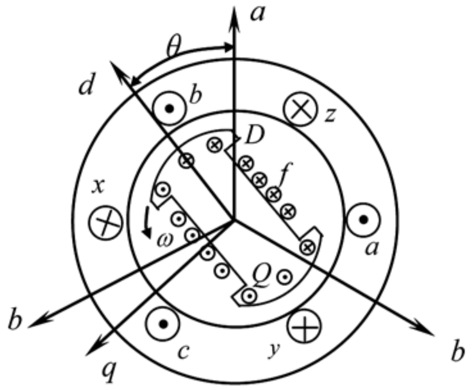

Fig.1 Structural schematic of salient pole synchronous generator

III.MATHEMATICAL MODELS OF SALIENT POLE SYNCHRONOUS GENERATOR

According to the structure and internal electromagnetic relationships of the synchronous generator, and also the electromagnetic dynamic run-time relationship, the voltage equation of the synchronous generator can be obtained in the (a, b, c) coordinate system as follow.

$$\begin{bmatrix} u_a \\ u_b \\ u_c \\ u_f \\ u_d \\ u_q \end{bmatrix} = \begin{bmatrix} -R & & & & & \\ & -R & & & 0 & \\ & & -R & & & \\ & & & R_f & & \\ & 0 & & & R_d & \\ & & & & & R_q \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \\ i_f \\ i_d \\ i_q \end{bmatrix} + \begin{bmatrix} \dot{\psi}_a \\ \dot{\psi}_b \\ \dot{\psi}_c \\ \dot{\psi}_f \\ \dot{\psi}_d \\ \dot{\psi}_q \end{bmatrix}$$

Where u_a,u_b , u_c ,u_f , u_d ,u_q means the voltage of three-phase stator windings, field winding and damper winding respectively and $\dot{\psi}_a - \dot{\psi}_q$ means the induced voltage of each winding, take a for example,

$$\psi_a = -L_{aa}i_a - M_{ab}i_b - M_{ac}i_c + M_{af}i_f + M_{aD}i_D + M_{aQ}i_Q$$

In order to analyze the problem conveniently, the reference coordinate system located in the rotor coordinate system is chosen, that is the Park transformation $i_{dq0} = Pi_{abc}$, when the generator is

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operated symmetrically, the zero-axis component is zero, P is the Park transformation matrix.

$$P=\frac{2}{3}\begin{bmatrix}\cos\theta & \cos(\theta-\frac{2}{3}\pi) & \cos(\theta+\frac{2}{3}\pi)\\ -\sin\theta & -\sin(\theta-\frac{2}{3}\pi) & -\sin(\theta+\frac{2}{3}\pi)\end{bmatrix}$$

Set flux equation can be abbreviated as

$$\begin{bmatrix}\psi_{abc}\\ \psi_{fdq}\end{bmatrix}=\begin{bmatrix}M_{ss} & M_{sr}\\ M_{rs} & M_{rr}\end{bmatrix}\begin{bmatrix}-i_{abc}\\ i_{fdq}\end{bmatrix}$$

So

$$\begin{bmatrix}\psi_{dq}\\ \psi_{DQ}\end{bmatrix}=\begin{bmatrix}P & 0\\ 0 & U\end{bmatrix}\begin{bmatrix}\psi_{abc}\\ \psi_{fDQ}\end{bmatrix}=$$

$$\begin{bmatrix}PM_{ss}P^{-1} & PM_{sr}\\ M_{rs}P^{-1} & M_{rr}\end{bmatrix}\begin{bmatrix}-i_{dq}\\ i_{fDQ}\end{bmatrix}$$

Where

$$PM_{ss}P^{-1}==\begin{bmatrix}L_d & \\ & L_q\end{bmatrix}$$

$$PM_{sr}=\begin{bmatrix}m_{af} & m_{aD} & 0\\ 0 & 0 & m_{aq}\end{bmatrix}$$

In which， U is the unit matrix.

$$M_{rr}=\begin{bmatrix}L_f & m_{fD} & 0\\ m_{fD} & L_D & 0\\ 0 & 0 & L_Q\end{bmatrix}$$

$$M_{rs}P^{-1}=\begin{bmatrix}\frac{3}{2}m_{af} & 0 & 0\\ \frac{3}{2}m_{aD} & 0 & 0\\ 0 & \frac{3}{2}m_{aQ} & 0\end{bmatrix}$$

The voltage equation showed by the Pike component is:

$$\begin{bmatrix}u_{dq}\\ u_{fDQ}\end{bmatrix}=\begin{bmatrix}R_s & 0\\ 0 & R_r\end{bmatrix}\begin{bmatrix}i_{dq}\\ i_{fDQ}\end{bmatrix}+\begin{bmatrix}\dot\psi_{dq}\\ \dot\psi_{fDQ}\end{bmatrix}+\begin{bmatrix}s\\ 0\end{bmatrix}$$

Where S is the rotation potential caused by coordinate transformation.

In the simulation calculation, the Per-unit value has many advantages compared with the standard value, such as clearer concept of relative, if the base value is selected appropriately, the mutual inductance between the stator and rotor can be made reversible, which simplifies the form of the state equation, and design parameters of the generator can be direct used. Therefore, the selection of Per-unit value is as follows: The stator side can be compared to the value of the rated capacity as base value; the Per-unit value system is used in the impedance of rotor side, in per unit values. In this Per-unit value system, all the elements of the coefficient matrix are time-invariant, so the voltage equation can be written directly:

$$u=A\dot i+Bi$$

Where

$\boldsymbol{i}=[i_d,i_q,i_f,i_D,i_Q]^{\mathrm{T}}$, $\boldsymbol{u}=[u_d,u_q,u_f,0,0]^{\mathrm{T}}$, $\boldsymbol{A}$ and $\boldsymbol{B}$ are determined by the structural parameters of the generator coefficient matrix.

$$\boldsymbol{A}=\begin{bmatrix}-x_d & 0 & x_{af} & x_{aD} & 0\\ 0 & -x_q & 0 & 0 & x_{aQ}\\ -x_{af} & 0 & x_f & x_{fD} & 0\\ -x_{aD} & 0 & x_{fD} & x_D & 0\\ 0 & -x_{aQ} & 0 & 0 & x_Q\end{bmatrix}$$

$$\boldsymbol{B}=\begin{bmatrix}-r & \omega x_q & 0 & 0 & -\omega x_{aQ}\\ -\omega x_d & -r & \omega x_{af} & \omega x_{aD} & 0\\ 0 & 0 & r_f & 0 & 0\\ 0 & 0 & 0 & r_D & 0\\ 0 & 0 & 0 & 0 & r_Q\end{bmatrix}$$

So the state Equation is

$$\dot i=-A^{-1}Bi+A^{-1}u$$

And this is the basis for simulation.

IV. SIMULATION ANALYSIS

In this paper, Matlab is used for the dynamic simulation of the generator, Figure 2 to Figure 4 are the voltage and current waveforms of dynamic and steady-state when a sudden three phase short circuit.

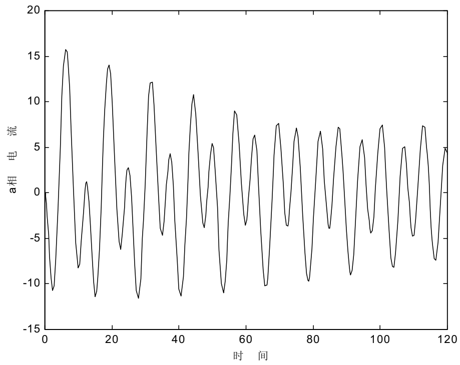

Fig.2 The waveform of current in phase a

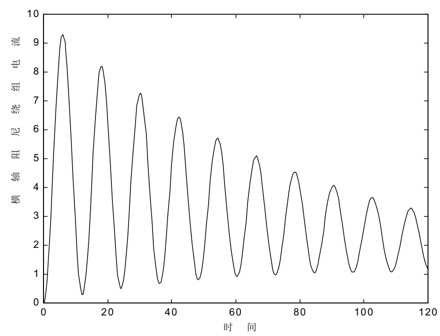

Fig.3 Waveform of current in horizontal axis damper winding

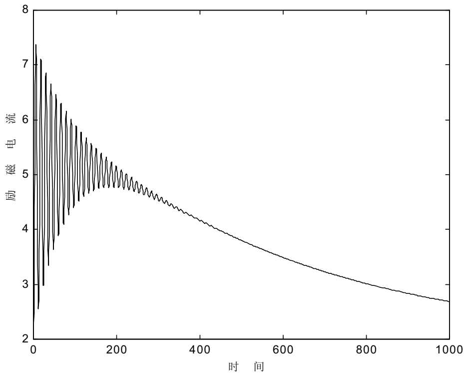

Fig.4 Variation of the field winding current

From the simulation results, In the three-phase short-circuit the armature instantaneous winding current of up to 16 times of the rated current, and then gradually tends to steady-state value, the initial value of excitation current is 2.25, the excitation current is close to 2.25 in stable operation.

V. CONCLUSION

The method for building mathematical model of the synchronous generator is Logical conceptual clarity, the generator parameters are non-time-varying and also *dq* parameters commonly used in engineering design, without any transformation. It can be applied directly in the ode23 Matlab numerical solution methods. The simulation result is satisfactory, and this method can be applied to salient pole synchronous generator. This provides a theoretical basis for optimal design of the synchronous generator.

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