Study on Short circuit Dynamic Process of Synchronous Generator Based on Matlab Simulation

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Abstract. Synchronous generator is a key equipment of power system. It is very important that analyzing exactly the short circuit dynamic process of synchronous generator for the alternator and power system protection. Based on an idealized synchronous generator, this paper analyzes its mathematical equations and builds a software simulation model using Matlab S-function. The simulation study of three phase short circuit is finished. The varieties of main parameters in short circuit dynamic process are revealed vividly by simulation results which prove to be accurate and effective.

1. Introduction
Synchronous generator is an important equipment in the power system. Its capacity is usually comparable to that of the power grid. The shock current generated in the short circuit fault may reach more than ten times of the rated current, which may have a serious impact on all the equipment in the power system[1]. In addition, in the process of short circuit failure, a large amount of electromagnetic force and electromagnetic torque are generated inside the motor, causing damage to the mechanical structure of the motor. Therefore, the analysis of the transient process of short circuit fault of synchronous generator can not only provide a reference for the reasonable design of motor, but also provide an important basis for the protection and safety design of power grid. Synchronous generator is a high order multivariable and strongly coupled complex system with multiple magnetic coupling relations. By using the powerful numerical calculation ability of modern computer, the digital simulation model of synchronous generator is established through the mathematical state equation of synchronous generator, and the corresponding numerical calculation method is used for simulation calculation, which is not only simple and accurate, but also can clearly and intuitively display the dynamic process of failure.

2. Brief description of transient process of three phase short circuit of synchronous generator
Synchronous generator is the most important and complex component in the power system. They are composed of multiple magnetic-coupled windings. Stator windings and rotor windings have relative motion. The armature magnetic potential does not change with time during steady and symmetric operation, and it rotates at a synchronous speed in space. It has no relative motion with the rotor, so it will not induce current in the rotor winding. When a sudden short circuit occurs, the stator current changes sharply in value, and armature reaction flux also changes with it, and induction current is generated in the rotor winding, which in turn influences the stator current change. The interaction of
stator and rotor winding currents is a remarkable feature of the transient process of sudden short circuit of synchronous generator[2].

When analyzing the transient process of the sudden three phase short circuit of synchronous generator, the superposition principle can be used, so that the sudden short circuit of the synchronous generator end is equivalent to adding a three phase voltage of the same magnitude but opposite direction at the end of the generator end. After a symmetric phase voltage is suddenly applied to the stator winding, the corresponding transient current will be generated in the stator winding to keep the magnetic chain of its passive closed circuit unchanged, and the transient current will be gradually reduced to a steady state value in accordance with a certain time constant.

When the generator is suddenly short circuited, the current of the stator windings will include the fundamental frequency component, the double frequency component and the DC component. When the stator current reaches steady state, the DC component and the octave component in the initial value of stator current will decay from its initial value to zero, while the fundamental frequency component will decay from its initial value to the corresponding stable value. Also, the DC component and the AC component of the same frequency are included in the rotor winding. After the attenuation factor is introduced, the d-axis and q-axis components of stator current are respectively:

\[
i_q = \frac{E_{d(0)}}{x_q} \exp(-\frac{t}{T_d}) + \frac{V_{d(0)}}{x_q} \exp(-\frac{t}{T_q}) \sin(\omega t + \delta_d)
\]

After transformation and finishing, the stator a phase current is obtained:

\[
i_a = \frac{E_{d(0)}}{x_d} \cos(\omega t + \alpha_d) - \left(\frac{E_{q(0)}}{x_d} - \frac{E_{q(1)}}{x_d}\right)(-\frac{t}{T_d}) \cos(\omega t + \alpha_q) + \left(\frac{E_{q(0)}}{x_q} - \frac{E_{q(1)}}{x_q}\right) \exp(-\frac{t}{T_q}) \cos(\omega t + \alpha_q) + \frac{V_{d(0)}}{x_d} \left(1 + \frac{1}{x_q} \right) \exp(-\frac{t}{T_d}) \cos(\delta - \alpha_d) + \frac{V_{q(0)}}{x_q} \left(1 - \frac{1}{x_d} \right) \exp(-\frac{t}{T_q}) \cos(2\omega t + \delta + \alpha_d)
\]

Current in the rotor winding:

\[
i_r = i_{r(1)} + \frac{x_{ad} x_{aq}}{x_{ad}} V_{d(0)} \cos \delta_d - \frac{V_{d(0)} x_{ad}}{x_{ad}} \exp(-\frac{t}{T_d}) - \frac{x_{ad} x_{aq} V_{q(0)}}{x_{ad}} \exp(-\frac{t}{T_q}) \cos(\omega t + \delta_q)
\]

In equations (1) to (3), \(x_d \backslash x_q\) is the longitudinal axis of stator winding/Horizontal axis synchronous reactance; \(x_f\) is the armature between the vertical axis winding to reflect the reactance; \(x_{ad} \backslash x_{aq}\) is the longitudinal axis of generator rotor\; the reactance on the horizontal axis; \(x_D \backslash x_Q\) Represents the reactance of damped winding D and Q; \(x_{adD}\) is the leakage resistance of D damping winding; \(x_f \backslash x_f^\prime\) respectively are vertical axis transient reactance/subtransient reactance; \(x_q^\prime\) is the horizontal axis subtransient reactance; \(E_q \backslash E_q^\prime\) is the transient potential and the subtransient potential of the horizontal axis are respectively; \(E_{d(0)} \backslash V_{d(0)}\) is the no-load potential and terminal voltage of the moment before the short circuit[3].
3. Numerical calculation of transient process of sudden three phase short circuit of synchronous generator

In the case of known generator parameters, the stator current and rotor current transient process expressions (2) and (3) after sudden three phase short circuit can be numerically analyzed by using Matlab, which will help to better understand the physical process of short circuit.

Suppose a synchronous generator with damping winding. \( P_N = 200 \text{MW} \), \( U_N = 13.8 \text{kV} \), \( x_d = 1.0 \), \( x_q = 0.6 \), \( x'_{d} = 0.3 \), \( x''_{d} = 0.21 \), \( x''_{q} = 0.31 \), \( r = 0.005 \), \( x_{s_f} = 0.18 \), \( x_{a} = 0.1 \), \( x_{a0} = 0.25 \), \( T_{d} = 5s \), \( T_{q} = 2s \), \( T_{q0} = 1.4s \). If the generator is idle and the terminal voltage is rated, a three phase short circuit suddenly occurs at the terminal. \( \alpha_0 = 0 \), the basic steps of using Matlab to calculate the stator current after a sudden three phase short circuit are as follows[4]:

1. Calculate the attenuation time constants of each. According to the references, \( T_{d} = 0.16s \), \( T_{q} = 0.72s \), \( T_{a} = 0.34s \), \( T_{q0} = 1.64s \).

Due to no-load time, \( E_{[0]} = E'_{[0]} = E''_{[0]} = V_{[0]} = 1 \), The expression of the stator current can be obtained by using equation (2):

\[
i_a = -\cos(ot + a_0) - 1.43e^{-2.97t} \cos(ot + a_0) - 2.34e^{0.608t} \cos(ot + a_0) + 4e^{-3.3t} \cos(-a_0) + 0.77e^{-3.3t} \cos(2ot + a_0)
\]

(4)

2. Run the m file program in Matlab to perform numerical calculation and drawing on equation (4):

After running the above program, the a-phase stator current, as well as the waveforms of the fundamental frequency component, the frequency multiplier component and the aperiodic component are shown in Fig.1 when the three phase short circuit suddenly occurs at the generator end, and the standard value of the impulse current after the short circuit is 9.1927.

![Figure 1. A phase stator current waveform diagram of a generator when a three phase short circuit suddenly occurs at the generator end](image)

When a three phase short circuit suddenly occurs at the generator end, the octave component of stator current is small (usually ignored in practical calculation). In order to be clear in figure 1, the value of its vertical coordinate is taken as [-1, 1], and the waveform is amplified accordingly.

4. Simulation method for transient process of short circuit of synchronous generator

For the above generator parameters, the Simulink simulation model is established, as shown in Fig.2.

In Fig.2, the synchronous generator adopts the p.u. standard synchronous generator module. According to the previous calculation, its parameters are set as shown in Fig.3.

The Three-phase transformer(Two Windings) model is adopted for the boost transformer T, and its parameter setting is shown in Fig.4.
Since the synchronous generator module is the output of current source, a load module with an active power of 5MW is connected in parallel at its port.

Before the simulation starts, the motor is initialized with Powergui module. Click the Powergui module to open the power flow calculation and motor initialization window, and set parameters as shown in Fig.5. In the figure, the synchronous generator is set as the balance node "Swing bus". After initialization, the two constant modules $P_m$ and $V_f$ connected to the input port of the synchronous generator module and "init.cond." in Fig.3 will be set automatically.

It can also be seen from Fig.5 that a phase current lags behind a phase voltage of 4.43. That is, the current and voltage waveform over zero difference of 0.25ms. Therefore, a three phase short circuit fault occurs when 0.02025s is set in the fault module ($\alpha_0=0$), other parameters are set by default.

Odel5s algorithm was selected[4], and the end time of simulation was 1s. At the beginning of simulation, the three phase stator current waveform after the three phase short circuit at the generator end is obtained, as shown in Fig.6. Among them, the impingement current standard value of a phase stator current is 9.1048, and the theoretical calculation value has a 0.95%
error. As shown in Fig.7, the d-axis and q-axis components $i_d$ and $i_q$ of the stator current after a short circuit are shown. And the simulation waveform of excitation current $i_f$.

**Figure.5** Powergui module power flow calculation are used to calculate the initial parameters

**Figure.6** The stator current simulation waveform diagram of a generator with three phase short circuit

**Figure.7(a)** Id current simulation waveform diagram of the generator end with three phase short circuit
5. Conclusion
By mathematical equations of synchronous generator and mathematical software of Matlab, the simulation model is established. It can accurately simulate all kinds of short circuit faults of synchronous generator. The simulation results are in conformity with the actual situation, and the simulation results can clearly show the fault transient process of the current, torque, angle of various electrical and mechanical parameters, such as volatility change. It is very important for engineers and technicians to understand fault details and analyze fault parameters, and can support short circuit protection design of the power system and engineering design of the synchronous generator[5][6].

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