Short Circuit Analysis of an Unloaded Synchronous Generator

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Abstract: This paper demonstrates the classical short circuit (SC) test of a synchronous machine. This simulation gives a full analysis of a sudden symmetrical short-circuit of an unloaded synchronous generator. The intention is to check the transient characteristics by short-circuiting the three terminals of an unloaded synchronous generator, and the solution is then extended in so that it can be applied to a loaded machine as well. The system is assumed to be unloaded before the fault occurs and that the magnitude and phase angles of all the generator internal emfs are the same. Although, the majority of the faults occurring in practice on a power system are unsymmetrical between the phases, the symmetrical fault is important because, although rarer, it is more severe.

Index Terms **- Transient characteristics, Symmetrical and Unsymmetrical faults, Short-circuit test, Unloaded synchronous generator.**

I. INTRODUCTION

The Short-circuit test, in which the three terminals of an unloaded synchronous generator are all short-circuited simultaneously, is a well-established method of checking its transient characteristics. A fault is defined as an abnormal condition or defect in the system. Basically, Symmetrical and Unsymmetrical are two types of faults that may occur in a system. The former which affects all the three phases and the latter in which either one or two phases is involved.

Although, majority of the faults are unsymmetrical, symmetrical ones are important as it is more rare and severe. To conduct the SC test, the machine must be running in steady-state in open-circuit conditions and this is achieved by adjusting the phase angle and magnitude of the machine voltage with respect to the source voltage so that the current in the machine is zero (negligible) in the steady-state.

The main objective is to study the transient, sub-transient as well as the stable responses of the armature current when a three-phase symmetrical short circuit occurs at the terminals of an unloaded synchronous generator. The concept of Sub-transient, Transient and Steady state arises in case of fault in an Alternator. When the system is short-circuited, the currents in all the three-phases rise rapidly to a high value of about 10 to 18 times of full load current. During the first two or three cycles, the current is high and the reactance is least. This is called sub-transient reactance denoted by X_d". These first few-cycles come under sub-transient state. After which, the decrement in the short circuit current is less rapid than the decrements during the first few cycles. This state is called the Transient State and the reactance in this state is called transient reactance denoted by X_d'. The circuit breaker contacts separate in the transient state. Finally, the transient dies out and the current reaches a steady sinusoidal state called the Steady State. The reactance in this state is called steady state reactance X_d. The dc components in the three phases are different; hence the short circuit is applied at 0.5056 s. It is chosen just for convenience so that the Phase A current does not have a dc component during the SC test. And it is assumed that there is no dc offset in the armature current. The solution then can be extended in so that it can be applied to a loaded machine as well.

II. SYSTEM ANALYSIS

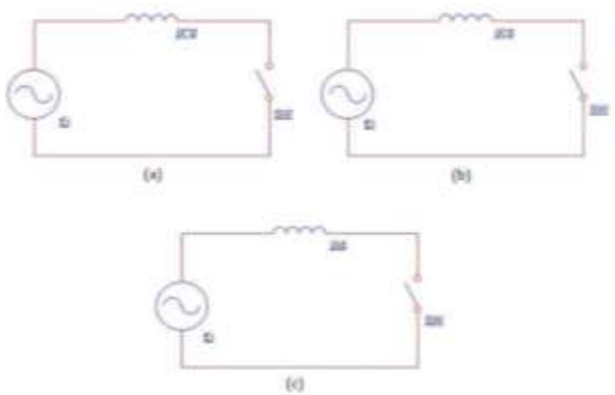

Fig. 1. Equivalent Circuit

The above Equivalent circuits are of synchronous generator with internal voltage of E_i and (a) Sub transient reactance X_d” (b) Transient reactance X_d’ (c) Synchronous reactance X_d

3.1 System Overview

In order to investigate the effect of various phenomena (e.g. faults) in the system, it is crucial that the system is initialized properly and is under proper steady-state load flow conditions.

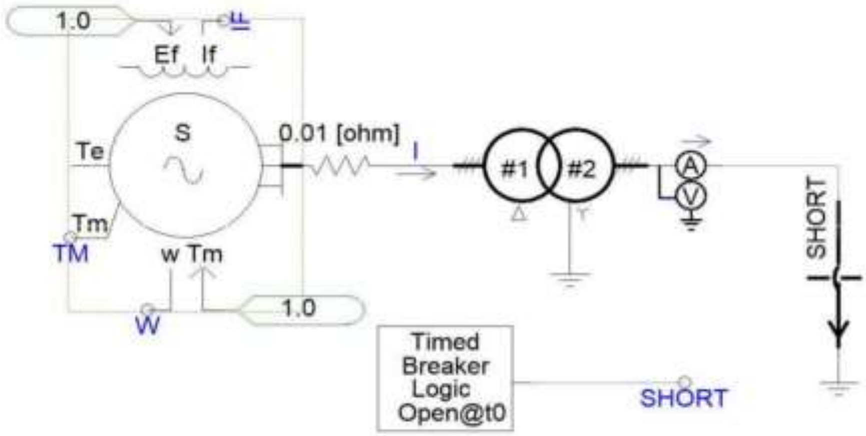

Fig. 2. PSCAD Model

In PSCAD, the recommended method of initializing the machine is to start it as a fixed voltage source and use this mode of operation to determine the exciter and governor input (or field voltage and mechanical torque) parameters needed to produce the desired steady-state condition.

3.2 Features

The initial conditions necessary to give the machine open-circuit conditions are as follows:

1. Voltage magnitude and phase of the infinite source is 230.0kV and 0.0^0

2. The same quantities for the machine are 13.8kV and

-31.08^0

3. Field voltage necessary to produce 1.0 PU terminal voltage on the open-circuit machine is 1.0 PU

The machine is run at constant speed by locking the rotor (Enab=0) at synchronous speed. Thus, there are no prime mover dynamics involved. The exciter dynamics are also eliminated by feeding a constant voltage (E_f=1.0 PU) to the exciter. Machine saturation is disabled. The ideal transformer is simply a ratio changer with negligible leakage reactance (0.005 PU) and no saturation. These simplifications allow us to focus primarily on the machine dynamics.

III. DESIGN CALCULATIONS

The relevant section of the machine parameters is shown in Table 1

Table 3.2.1: Generator Data Format of a 13.8kV 120 MVA Machine

Parameters	***2-Pole Machine***	***4-Pole Machine***	***Salient Pole Generator***
Unsaturated Reactance [Xd]	1.95 p. u	1.87 p. u	1.00 p. u
Unsaturated Transient Reactance [Xd’]	0.33 p. u	0.41 p. u	0.32 p. u
Unsaturated Sub-Transient Reactance [Xd”]	0.28 p. u	0.29 p. u	0.2 p. u
Unsaturated Transient Time (Open) [Td0’]	6.55 s	6.55 s	6.55 s
Unsaturated Sub-Transient Time (Open) [Td0’’]	0.039 s	0.039 s	0.039 s

IV. SIMULATION RESULTS

The theoretical time constants for the given machine parameters with the time constants, as demonstrated by the simulation graphs.

4.1 For a 2 Pole Machine

Sub-transient Time constant:

$$Td'' = \left(\frac{Xd''}{Xd'}\right) Td_0'' \qquad (1)$$

$$Td'' = \left(\frac{0.28}{0.33}\right) 0.039$$

$$Td'' = 33.09\text{ms}$$

Transient Time constant:

$$Td' = \left(\frac{Xd'}{Xd}\right) Td'_0 \qquad (2)$$

$$Td' = \left(\frac{0.33}{1.95}\right) 6.55$$

$$Td' = 1.108s$$

Field Current:

Assume If_0=1.0 P.U & Field current will decay to around 37% of its initial value.

$$If'_0 = \left(\frac{Xd}{Xd'}\right) If_0 = \left(\frac{1.95}{0.33}\right) 1.0 = 5.909 \text{ P.U}$$

$$If' = If_0 + (If'_0 - If_0)e^{-\frac{t}{Td'}} = 1 + (5.909 - 1)0.37 = 2.8163 \text{ P.U}$$

Graphs:

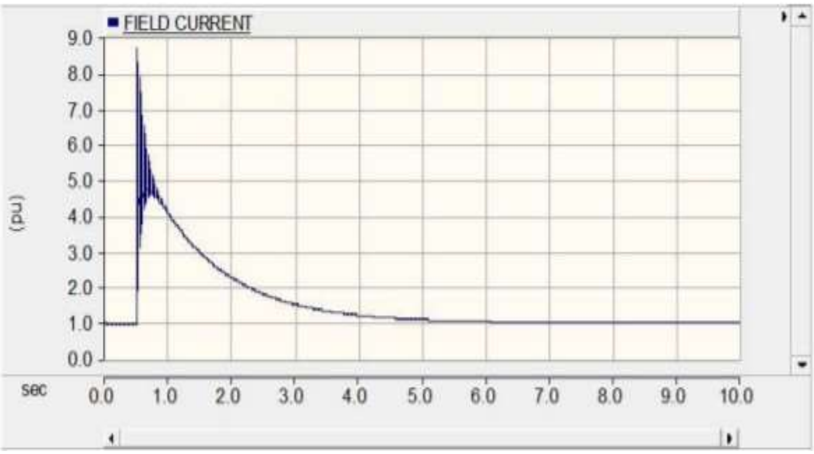

Fig. 3. Field current of a 2-Pole Machine

The short circuit current is the current flowing in the armature of a synchronous generator when its terminals are short circuited is similar to that flowing when a sinusoidal voltage is suddenly applied to an R-L series circuit. However, there is one important difference, that is, in case of a R-L series circuit, reactance X (ωL) is a constant quantity where as in case of the synchronous generator the reactance is not a constant one but is a function of time.

The short circuit of the 2-pole machine obtained after the simulation is demonstrated in the figure below:

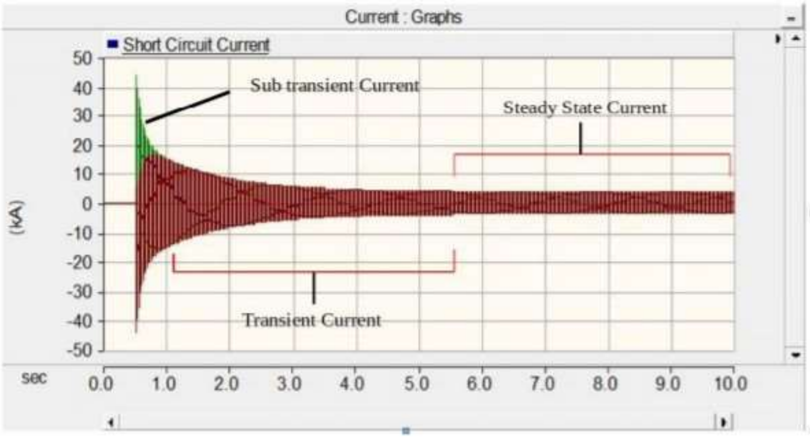

Fig. 4. Short circuit current of a 2-Pole Machine

4.2 For a 4-Pole Machine

Sub-transient Time constant:

$$Td'' = \left(\frac{Xd''}{Xd'}\right) Td_0''$$

$$Td'' = \left(\frac{0.29}{0.41}\right) 0.039$$

$$Td'' = 27.585\text{ms}$$

Transient Time constant:

$$Td' = \left(\frac{Xd'}{Xd}\right) Td_0'$$

$$Td' = \left(\frac{0.41}{1.87}\right) 6.55$$

$$Td' = 1.436\text{s}$$

Field Current:

Assume If_0=1.0 P.U & Field current will decay to around 37% of its initial value.

$$If_0' = \left(\frac{Xd}{Xd'}\right) If_0 = \left(\frac{1.87}{0.41}\right) 1.0 = 4.5609\ \text{P.U}$$

$$If' = If_0 + (If_0' - If_0) e^{-\frac{t}{Td'}} = 1 + (4.5609 - 1)0.37 = 2.3175\ \text{P.U}$$

Graphs:

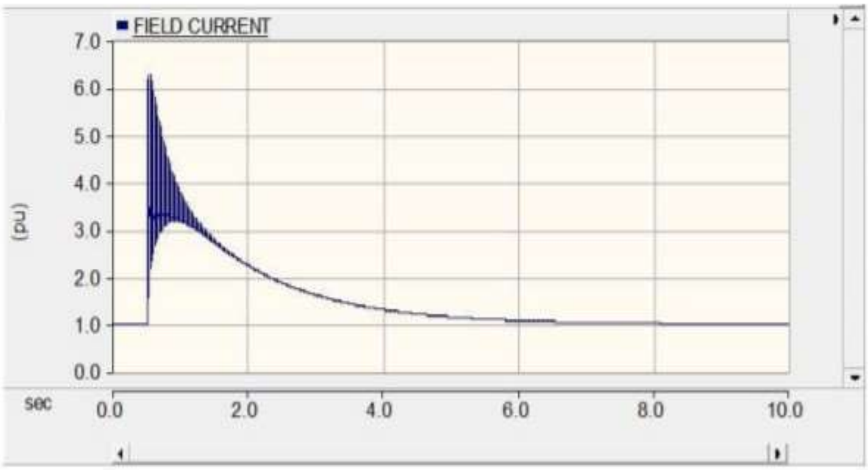

Fig. 5. Field current of a 4-Pole Machine

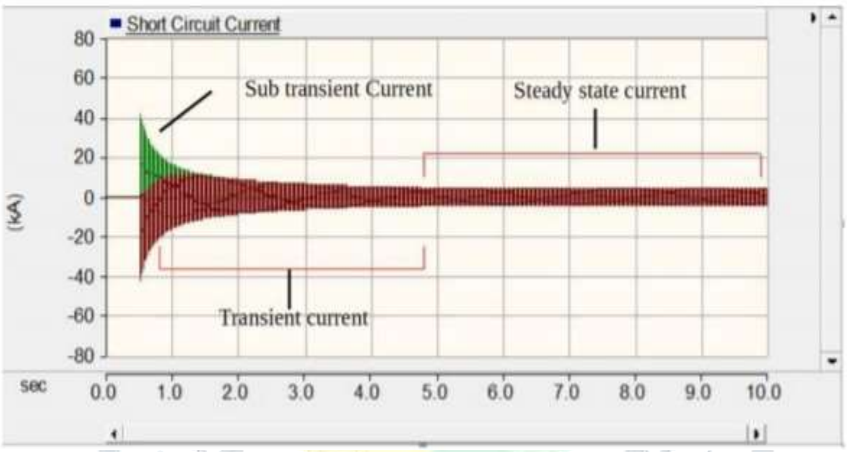

Fig. 6. Short circuit current of a 4-Pole Machine

4.3 Salient Pole Generator With Dampers

Sub-transient Time constant:

$$Td'' = \left(\frac{Xd''}{Xd'}\right) Td_0''$$

$$Td'' = \left(\frac{0.2}{0.32}\right) 0.039$$

$$Td'' = 24.375ms$$

Transient Time constant:

$$\mathrm{Td}' = \left(\frac{\mathrm{Xd}'}{\mathrm{Xd}}\right)\mathrm{Td}_0'$$

$$\mathrm{Td}' = \left(\frac{0.32}{1.00}\right)6.55$$

$$\mathrm{Td}' = 2.096\mathrm{s}$$

Field Current:

Assume If_0=1.0 P.U & Field current will decay to around 37% of its initial value.

$$\mathrm{If}_0' = \left(\frac{\mathrm{Xd}}{\mathrm{Xd}'}\right)\mathrm{If}_0 = \left(\frac{1.00}{0.32}\right)1.0 = 3.125\ \mathrm{P.U}$$

$$\mathrm{If}' = \mathrm{If}_0 + (\mathrm{If}_0' - \mathrm{If}_0)e^{-\frac{t}{Td'}} = 1 + (3.125 - 1)0.37 = 1.7862\ \mathrm{P.U}$$

Graphs:

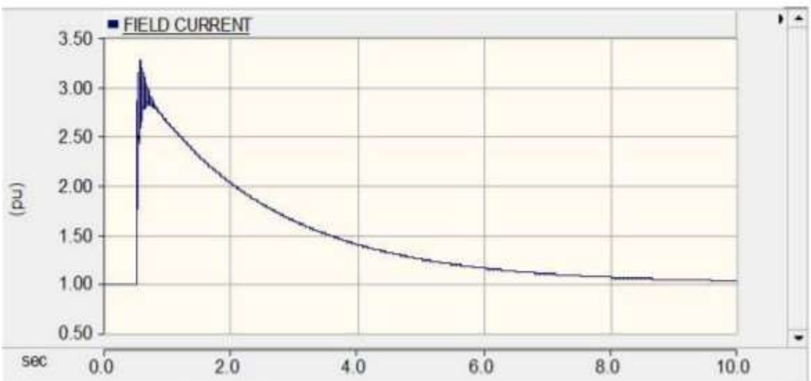

Fig. 7. Field current of Salient Pole Generator with Dampers

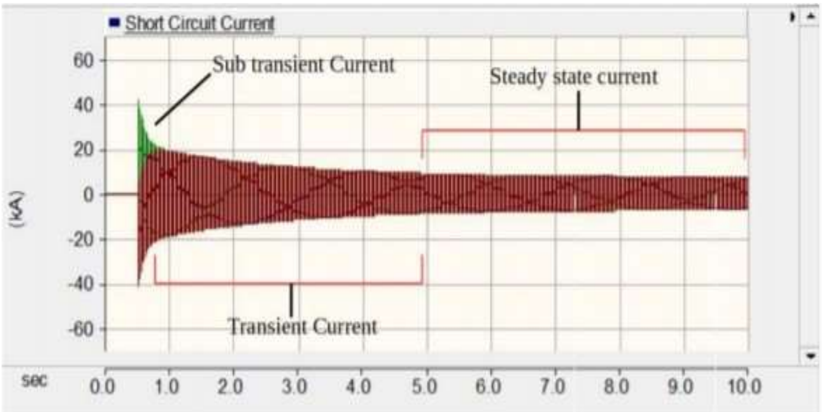

Fig. 8. Short circuit current of Salient Pole Generator.

V. CONCLUSION

The theoretical results and the simulation results are very close. Therefore, the model of the synchronous machine is accurately represented in PSCAD. When a fault occurs in a power network, the current flowing is determined by the internal emfs of the machines in the network, by their impedances, and by the impedances in the network between the machines and the fault. The current flowing in the synchronous machine immediately after the occurrence of the fault differs from that flowing a few cycles later and from the sustained, or steady state, value of the fault current. This is because of the effect of the fault current in the armature on the flux generating the voltage in the machine. The relative current slowly changes from its initial value to its steady state value owing to the changes in the reactance of the synchronous machine.

VI. ACKNOWLEDGMENT

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