Modeling and Fault Simulation of Generator Control System using PSCAD/EMTDC

Y. S. Kim, Y. Y. Park, K. M. Lee, H. J. Lee, C. W. Park

Abstract--**In this paper, a generator control system by using PSCAD/EMTDC software was modeled and several fault simulations were performed. The generator control system is composed of generator, turbine, exciter and governor. The parameters of the generator control system model were obtained from field power plant. Also, the various transient phenomena obtained through several signals of the developed modeling and fault simulation were analyzed.**

***Keywords*: exciter, fault simulation, generator control system, governor, modeling, PSCAD/EMTDC, transient phenomena, turbine.**

I. INTRODUCTION

Large generator of power plant is one of the important elements in power system. Even though the occurrence of generator fault is less than the one of transmission and substation facility faults, those incidents caused by the generator faults have had a big impact on our daily life. In order to protect large generator from faults and abnormal operating conditions during service of elements of power system, digital generator protection system is required.

However, all protective devices or IEDs for large generators of the domestic power plant in South Korea have been operated by foreign products. For technological independence from foreign and improvement of import substitution effect, digital generator protection system using domestic technology is being developed [1,2]. To evaluate performance of developing next-generation generator protective devices, the study on the dynamic characteristics of the power plant, generator control system modeling, fault simulation and analysis, should be considered. Furthermore, to obtain IEEE Standards COMTRADE (IEEE Standard Common Format for Transient Data Exchange) format for relay operation test, generator system modeling and fault simulation using PSCAD/EMTDC tools must be preceded.

In South Korea, in the early days, EMTP was introduced as a tool of power system dynamics analysis. Recently, EMTP-RV, ATP, PSCAD/EMTDC, Powersim, and MATLAB/SIMULINK have been applied. An implementation of generator protective relay for RTDS (Real Time Digital Simulator) was performed [3]. A study on protection method for CES (Community Energy System) using REX-10 was published [4]. The characteristic analysis of frequency in 765[kV] transmission system using EMTP-RV [5] was studied. For wide-area protection relaying, 345[kV] system modeling using the EMTP-RV was done [6,7]. Modeling and fault simulation of two generator system using MATLAB/SIMULINK was conducted [8]. Dynamic characteristic analysis of water-turbine generator control system of the 00 tidal power plant using the PSS/E was performed [9].

In this paper, a generator control system by using PSCAD/EMTDC was modeled and several fault simulations were performed [10,11]. The generator control system is composed of generator, turbine, exciter and governor. The parameters of the generator control system model were obtained from field power plant [12]. The various transient phenomena obtained from the developed modeling and fault simulation were analyzed.

II. MODELING OF HYDRO GENERATOR CONTROL SYSTEM

A generator control system model comprises a synchronous generator, a hydro turbine with governor, and a excitation. Generator receives the mechanical torque input through the turbines. Exciter controls the voltage of the generator and governor controls the turbine speed. The generator control system is established in PSCAD/EMTDC software. The parameters of the generator control system model were obtained from field power plant in South Korea. For the study, the capacity of the selected synchronous generator is 120[MVA], the rated RMS phase voltage is 13.856[kV], rated RMS phase current is 2.887[kA], and reference angular frequency is 376.99[rad/sec]. The total simulation time of modeling is 50[sec], the simulation time was 104.167[μsec].

We selected that generator is hydro synchronous generator

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type, exciter model is IEEE ST1A (Static Excitation System #1) type, hydro turbine model is TUR1 (Non-Elastic Water Column with Surge Tank) type, and governor model is GOV1 (Mechanical Hydraulic Controls) type. Synchronous generator model parameter is shown in Table 1. Exciter model parameter is shown in Table 2. Hydro turbine model parameter is shown in Table 3. Governor model parameter is shown in Table 4.

TABLE I

SYNCHRONOUS GENERATOR MODEL PARAMETER

Generator Data Format	
Armature Resistance[Ra]	0.005[pu]
Portier Reactance [Xp]	0.163[pu]
D: Unsaturated Reactance [Xd]	0.9631[pu]
D: Unsaturated Transient Reactance [Xd']	0.3447[pu]
D: Unsat. Transient Time (Open) [Tdo']	7.1800[s]
D: Unsat. Sub-Transient Reactance [Xd"]	0.2857[pu]
D: Unsat. Sub-Transient Time (Open) [Tdo"]	0.0700[s]
Q: Unsaturated Reactance [Xq]	0.6973[pu]
Q: Unsat. Sub-Transient Reactance [Xq"]	0.2857[pu]
Q: Unsat. Sub-Transient Time (Open) [Tqo"]	0.1100[s]
Air Gap Factor	1

TABLE II

SYNCHRONOUS GENERATOR MODEL PARAMETER

St1A Feedback & Regular Parameters	
Rate Feedback Gain (KF)	0.005[pu]
Rate Feedback Gain (KF)	0.03[pu]
Rate Feedback Time Constant (TF)	1.0[s]
Regular Gain (KA)	300.0[pu]
Regular Time Constant (TA)	0.051[s]
Maximum Regular Output (VAMAX)	999.[pu]
Minimum Regular Output (VAMIN)	-999[pu]
St1A Field Circuit Constants	
Exct. Output Current Limit Refer. (ILR)	4.4[pu]
Exct. Output Current Limit Gain (KLR)	4.54[pu]
Maximum Field Voltage (VRMAX)	5.9[pu]
Minimum Field Voltage (VRMIN)	-4.8[pu]
Exciter Voltage Supply	Bus Fed
Field Current Commutating Imp. (KC)	0.175[pu]
Upper Limit on Error Signal (VMAX)	0.2[pu]
Lower Limit on Error Signal (VMIN)	-0.1[pu]

TABLE III

WATER TURBINE MODEL PARAMETER

Tur1: Non_Elastic Water Column & No Surge Tank	
Rate Feedback Gain (KF)	0.005[pu]
Water Starting Time (TW)	2.0[s]
Penstock Head Loss Coefficient (fp)	0.02[pu]
Turbine Damping Constant (D)	0.2[pu]

TABLE IV

GOVERNOR MODEL PARAMETER

Gov1: Mechanical-Hydraulic Governor	
Rate Feedback Gain (KF)	0.005[pu]
Pilot Valve_Servomotor Time Constant (Tp)	0.05[s]
Servo Gain (Q)	5.0[pu]
Main Servo Time Constant (Tg)	0.5[s]
Temporary Droop (Rt)	0.5[pu]
Reset or Dashpot Time Constant (TR)	6.0[s]

III. HYDRO GENERATOR FAULT SIMULATION

A. *Fault simulation of voltage restrained relay*

A simple time overcurrent relay cannot be properly set to provide adequate backup protection. In case the difference in the maximum load current and the minimum fault current is small, if the conventional overcurrent relay is set to avoid malfunction due to a load current, then the relay goes wrong or takes a long time during fault conditions. Accordingly, the irrational action in relay coordination can occur. However, in such a case, this voltage restrained overcurrent relay can selective block action. If the circuit voltage is normal, it is difficult to operate relay because restraint force is strong. But, in fault conditions, relay is easy to operate because the circuit voltage is lowered and thus the restraint force is weak. As fault inception point is closer to generator, restraint voltage becomes small. Therefore, the relay operates at a high sensitivity.

This study carries out simulation on two fault resistance values (0.0001[Ω] and 1[Ω]). Fault simulation for the voltage restrained overcurrent relay is shown in Figure 1.

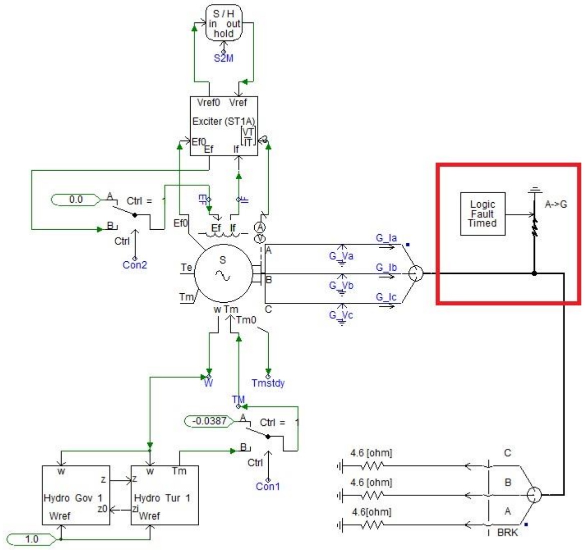


Fig. 1. Fault simulation of voltage restrained overcurrent relay

The fault simulation of fault resistance at 0.0001[Ω] is shown in Figure 2, and the fault simulation of fault resistance at 1[Ω] is shown in Figure 3. Fault inception time was selected to 20[sec]. From Figure 2, because the fault resistance is very small, we can see that the voltage becomes zero after fault occurrence. From Figure 3, as the fault resistance is increased, it can be seen that the magnitude of the fault voltage is increased. Since the restraint voltage is smaller as the fault resistance is large, the relay during high impedance ground fault can operate more sensitively. Voltage restrained relay should be set to coordinate with system line relay for close-in faults on the transmission lines at the power plant.

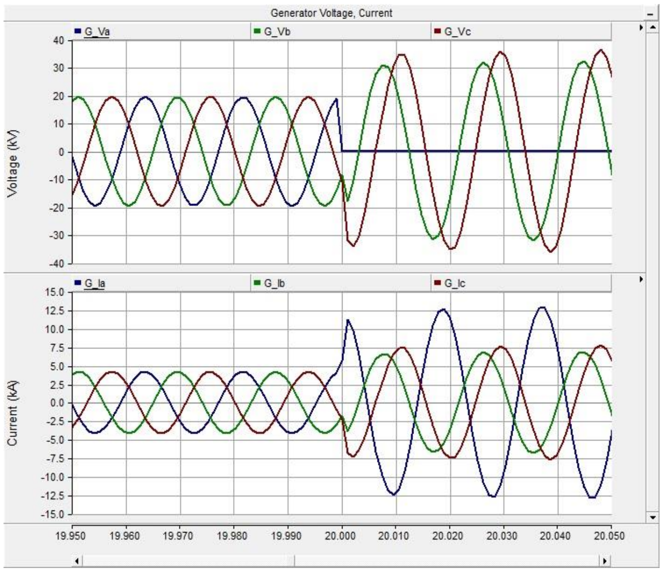


Fig. 2. Fault simulation of fault resistance at 0.0001[Ω]

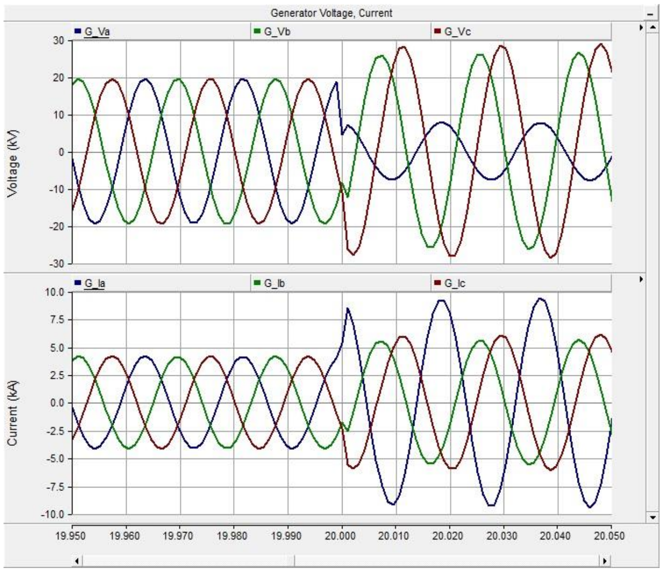


Fig. 3. Fault simulation of fault resistance at 1[Ω]

B. Fault simulation of negative sequence current

There are many conditions, untransposed lines, unbalanced loads, unbalanced system faults, and open phases, that may cause unbalanced three phase currents in a generator.

Fault simulation of the negative sequence current is shown in Figure 4. In this study, we simulated various unbalance faults that can cause the negative sequence current in a generator. Here we discuss only A phase to ground fault of the generator terminals.

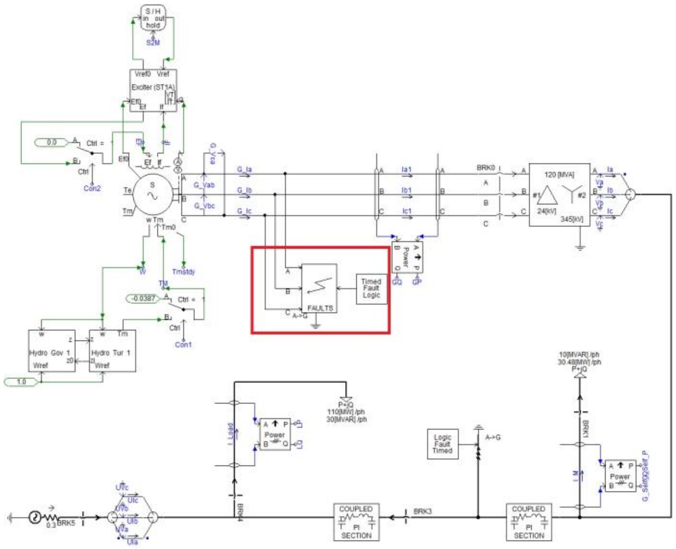


Fig. 4. Fault simulation of negative sequence current

We assume that the A phase to ground fault at the generator terminal has occurred at 20[sec] and lasted for 4[sec]. The three phase fault current during the A phase ground fault is shown in Figure 5. From Figure 5, we can see that the instantaneous value of three phase symmetrical current is flowing in the normal state. After fault, we can see that the A phase current is increased, and then become to unbalance states.

The negative sequence current computed by method of symmetrical coordinates is shown in Figure 6. From Figure 6(a), during A phase to ground fault, we can see that the negative sequence current of CT secondary side is gradually increased from the fault occurrence time 20[sec]. From Figure 6(b), during AB phase to short fault, we can see that the negative sequence current of CT secondary side is severely increased from the fault occurrence time 20[sec]. Negative sequence current can induce a double frequency current in the surface of the rotor, the retaining rings, and the slot wedges in the field winding. Therefore, the rotor currents may cause high and possibly dangerous temperatures.

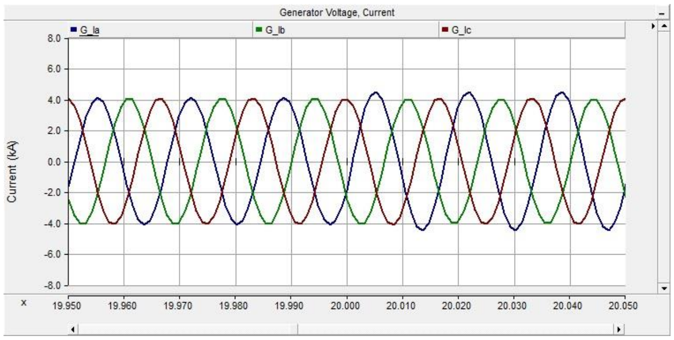
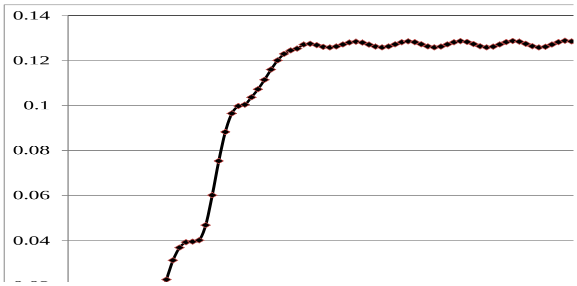
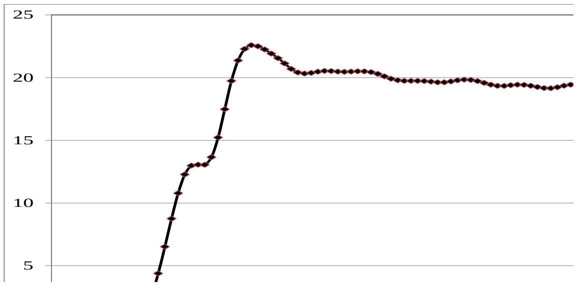


Fig. 5. Current signal of A phase ground fault



(a) A phase to ground fault



(b) AB phase to short fault

Fig. 6. Negative sequence current

C. *Fault simulation of reverse power*

Motoring is defined as the flow of real power into the generator acting as a motor. The prime mover may be damaged during a motoring operation condition. So the prime mover must be protected. Fault simulation of motoring is shown in Figure 7. Fault simulation of reverse power was carried out by varying the input torque of turbine, from 1[pu] to -0.05[pu].

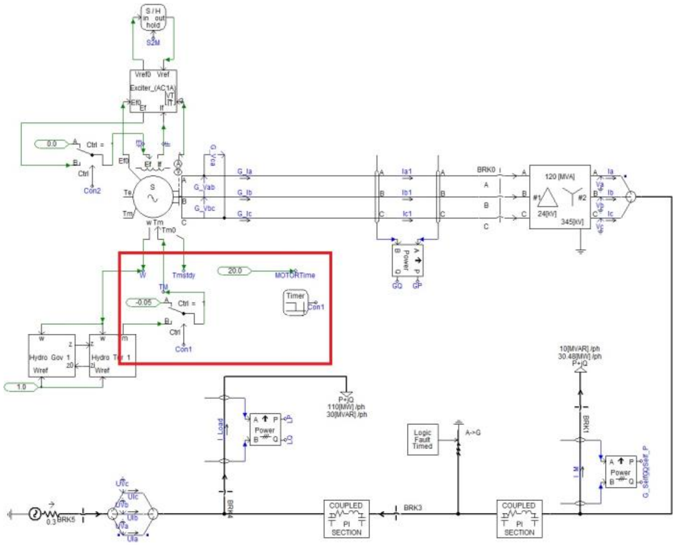
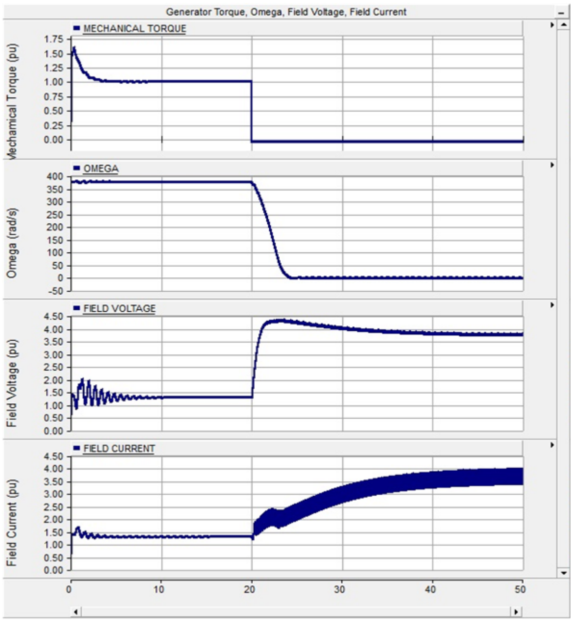
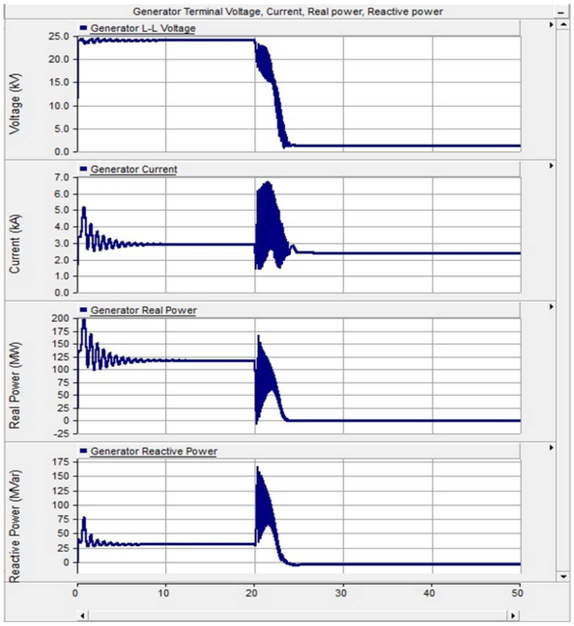


Fig. 7. Fault simulation of reverse power

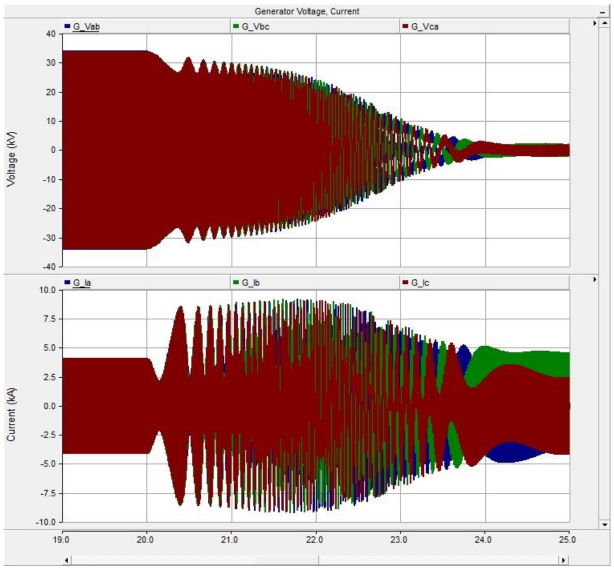
Various signals of the generator are shown in Figure 8. At 20[sec] as shown in Figure 8, the mechanical input torque was changed from 1[pu] to 0.05[pu]. Also the angular speed was reduced significantly from the normal speed. At last, the angular speed was to be zero. After fault inception, we can see that the field voltage rose up to 4.4[pu], and then decreased. Also we can see that the field current was oscillating to increase. The rated RMS phase voltage of generator terminal was 13.856[kV] during normal state. But after fault inception, we can see that the line to line voltage of generator terminal was decreased severely, also generator current was decreased, and then output was reduced significantly. In particular, after fault inception, it is shown that the active power of generator decreased, and the reverse power of about -5[MW] was generated. This motoring may cause many undesirable conditions. Accordingly, it must block the input of the prime mover, and be separated from the power system.



(a) Mechanical torque, omega, field voltage, and field current



(b) Voltage, current, real power, and reactive power



(c) Voltage, current, real power, and reactive power

Fig. 8. Several signals

IV. CONCLUSIONS

In this paper, a generator control system by using PSCAD/EMTDC was modeled and various fault simulations were performed. The various transient phenomena were analyzed by using the data obtained from fault simulation. We confirmed that voltage restrained overcurrent relay could be designed to restrain operation during overload conditions. Also, through unbalanced faults simulation of generator terminal faults, it was confirmed that the negative sequence current increased and thus could lead to damage by overheating the rotor. Finally, from the reverse power simulation of the generator, the results on undesirable motoring phenomenon were investigated.

In near future, the fault simulation data will be converted into COMTRADE format to be used in the development and test of digital integrated protective relay system for hydroelectric generators.

V. ACKNOWLEDGMENT

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