Proceedings of the Sixth IASTED International Conference
EUROPEAN POWER AND ENERGY SYSTEMS
June 26–28, 2006, Rhodes, Greece

ENHANCEMENT OF TRANSIENT STABILITY USING FAULT CURRENT LIMITER AND BRAKING RESISTOR

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ABSTRACT
This paper presents the results of analyses about transient stability enhancement using both devices-the fault current limiter and the braking resistor. Following a major disturbance in power system, the fault current limiter operates for limiting of the fault current and enhancement of the transient stability, and then the thyristor controlled braking resistor operates with the objective of fast control of generator disturbances. This paper also presents the results of analyses of the effectiveness of both devices on suppression of the turbine shaft torsional oscillations. These analyses are performed using EMTP/ATP. The simulation results indicate a significant transient stability enhancement and damping shaft torsional oscillations.

KEY WORDS
Fault current limiter, thyristor controlled braking resistor, transient stability, turbine shaft torsional oscillation

1. Introduction

As electric power systems grow and become more interconnected, the fault currents increase, and transient stability problems become more serious. Consequently, in order to maintain the stability of power system, replacement of substation equipment or changes in the configuration of the system will be needed, and this ultimately leads to decreased operational flexibility and lower reliability.

The use of Fault Current Limiters (FCLs) is being evaluated as one element necessary to limit the fault current and enhance the power system transient stability[1-3]. FCL is a device that limits the fault current by generating an impedance when a fault occurs. In addition, the limiting impedance generated to limit fault currents proves helpful in increasing generator output degraded by a fault, thus providing stabilization. However, as FCLs installed in series with transmission lines can be just operated during the period from the fault occurrence to the fault clearing, they cannot control the generator disturbances after the clearing of fault.

The Braking Resistor (BR) is also known as a very effective device for transient stability control. It can be viewed as a fast load injection to absorb excess transient energy which arises due to system disturbances. Besides, with the recent development of power electronics technology, replacing the circuit breaker with the semiconductor device is becoming feasible. Several thyristor-based control techniques [4, 5] have been proposed in the literature for the switching of BR. Since the thyristor controlled braking resistor (TCBR) can control the accelerating power in generators with flexibility, the power system stability is enhanced more than that of the use of BR controlled by mechanical device. However, as BR is installed in parallel with the transmission lines, BR cannot be operated before the clearing of faults.

From these viewpoints, in this paper, we have proposed the use of both devices-FCL and TCBR for the purpose of a significant transient stability enhancement. If both devices-FCL and TCBR operate at the same bus, the stabilization control scheme can be carried out continuously and with flexibility for a long duration (i.e., FCL operates from the fault occurrence instance to the fault clearing, and then TCBR operates dynamically until the generator disturbance becomes small). Through the simulation results, the effectiveness of the use of both devices on transient stability enhancement is demonstrated. This paper also presents the effectiveness of the use of both devices on suppression of the turbine shaft torsional oscillations. Simulations are performed using EMTP/ATP.

2. Power System Model

The power system model used for the simulation is shown in Fig. 1. The model system consists of a synchronous generator, SG, feeding an infinite bus through a transformer and double circuit transmission line. The TCBR with a conductance value of G_{TCBR} is connected to the high tension side of the step-up transformer through the thyristor switching circuit. The FCL is installed at the line side of the same bus. To analyze the turbine shaft torsional phenomenon, 6-mass system as shown in Fig.2 is modeled. Tables 1 and 2 show the synchronous generator parameters and turbine shaft parameters [6]

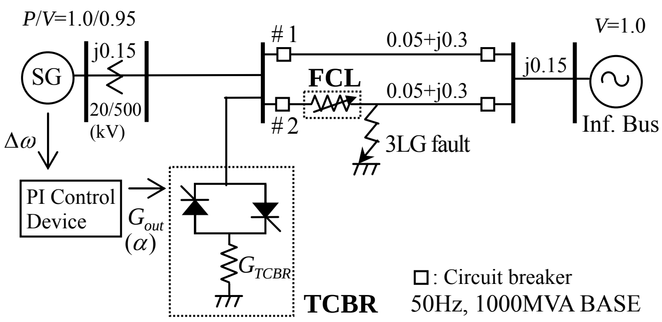


Fig.1 Power System Model.

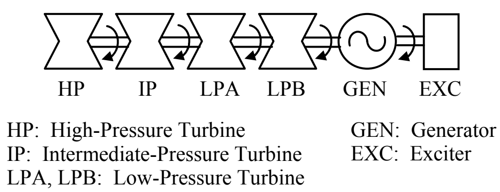


Fig.2 Turbine-Generator Shaft Model.

Table 1 Generator Parameters.

Generator Rating (MVA)					1000.0
r_a	(pu)	0.003	X''_q	(pu)	0.2
X_l	(pu)	0.13	X_0	(pu)	0.13
X_d	(pu)	1.79	T'_{d0}	(sec)	4.3
X_q	(pu)	1.71	T'_{q0}	(sec)	0.85
X'_d	(pu)	0.169	T''_{d0}	(sec)	0.032
X'_q	(pu)	0.228	T''_{q0}	(sec)	0.05
X''_d	(pu)	0.135	H	(sec)	2.89

Table 2 Turbine Shaft Parameters.

	Inertia constant (s)	Spring constant (pu T/rad)
HP Turbine	0.092897	19.303
LP Turbine	0.155589	34.929
LPA Turbine	0.858670	52.038
LPB Turbine	0.884215	70.858
Generator	0.868495	2.82
Exciter	0.034216	

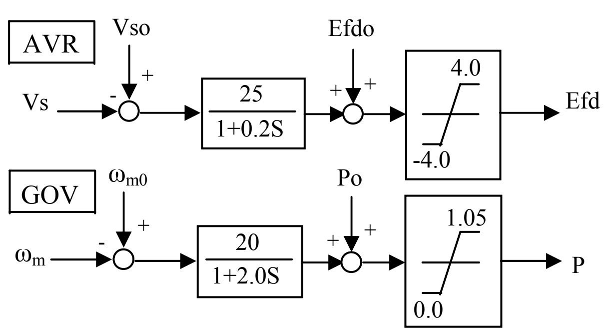


Fig. 3 AVR and Governor Models.

respectively. The models of AVR and governor are shown in Fig.3.

In the simulation study, it has been considered that the three-lines-to-ground (3LG) fault occurs near the generator at line #2 at 0.1 sec, the circuit breakers are opened at 0.2 sec, and at 1.2 sec the circuit breakers are closed. It is assumed that the circuit breakers clear the line when the current through it crosses the zero level.

3. Modeling of FCL

A variety of FCLs with various approaches to limiting current have been developed and tested. The FCL conceived of in this paper consists of a detector, a controller, and a limiting resistance, all common hardware found in an FCL of any type. Fig. 4 shows the changes over time for the limiting resistance created in an FCL. It is assumed that the limiting resistance value is 1.4 pu, and the fault detection time and starting time of limiting resistance are 2 msec and 1 msec respectively [1]. Namely, FCL starts to operate at 0.102 sec, and then the limiting resistance increases linearly from 0.0 pu to 1.4 pu within 1 msec. Although the effect of enhancement of transient stability is changed depend on the limiting resistance value, 1.4 pu is the most effective value on the transient stability enhancement which is determined based on the results of simulation using various limiting resistance values.

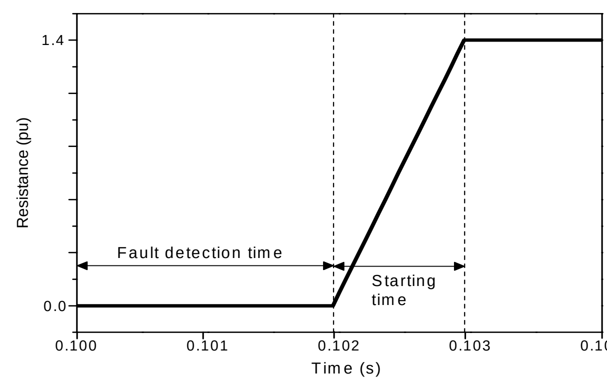


Fig. 4 Limiting Resistance Characteristics.

4. Modeling of TCBR

As shown in Fig.1, the generator speed deviation, $\Delta\omega$, and the desired conductance value of BR, G_{out}, are selected as the input and output respectively. Following a fault in power system, the rotor speed deviation, $\Delta\omega$, of the generator is measured, and then the desired conductance value, G_{out}, is determined by PI controller. PI controller is designed based on control rules as follows: (1) If $\Delta\omega$ is large, G_{out} is determined so that the power dissipated in BR becomes also large, (2) If $\Delta\omega$ is small, G_{out} is determined so that the power dissipated in BR becomes also small, and (3) If $\Delta\omega$ is less than 0.001 pu, G_{out} is zero (α =180 degree). For the fast control of the generator disturbances, we have tuned the controller parameters by trial and error method.

Firing-angle, α , for the thyristor switch is calculated from the output of the PI controller (i.e., G_{out}). The desired power consumption determined by G_{out} and the real power consumption determined by G_{TCBR} are equal and hence firing-angle, α , can be calculated from the following power equation.

$$\frac{V^2 G_{TCBR}}{\pi}\left(\pi - \alpha + \frac{1}{2}\sin 2\alpha\right) = V^2 G_{out} \qquad (1)$$

Where V is the rms value of the generator terminal bus voltage and G_{TCBR} is specified to 1.0 pu. However, the firing-angle, α , cannot be directly calculated from eq.(1) since it includes a trigonometric function. So, in this simulation, firstly by using eq.(1), a set of different values of G_{out} is calculated for the values of firing-angle ranging from 0 to 180 degrees with a step of 2 degrees. Then by using the linear interpolation technique, firing-angle, α , is determined.

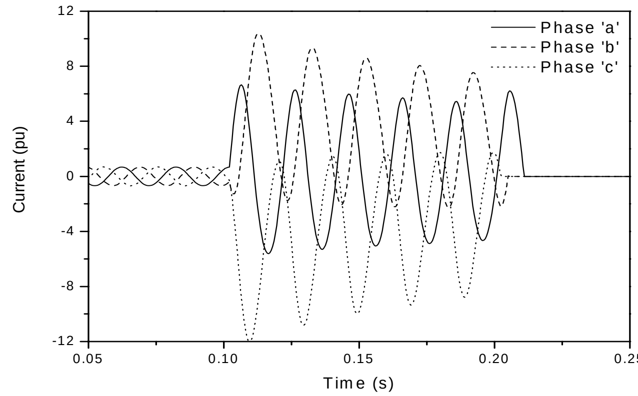
5. Simulation Results

5.1 Limitation of Fault Current

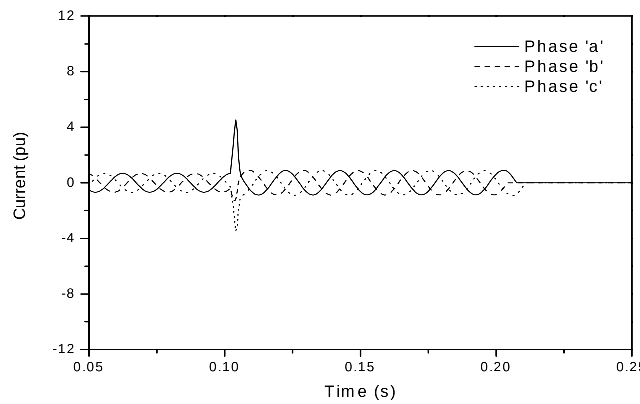
Fig. 5 shows the current waveforms flowing into the faulted line. In case of “no devices”, the fault currents rise up significantly and DC component in the current decreases slowly. On the other hand, in case of “with the both devices of FCL and TCBR”, the fault currents are limited and the DC component decreases rapidly by the limiting resistance of FCL.

5.2 Enhancement of Transient Stability

Fig. 6 shows the load angle responses in each case: (a) no devices, (b) with only FCL, (c) with only TCBR, and (d) with both devices of FCL and TCBR. In case of “no devices”, the generator becomes out of step due to 3LG fault near the generator. On the other hand, in case of “with devices”, the generator is advancing towards a stable condition as shown in Figs. 6 (b)-(d). In case of “with FCL”, the load angle swing is effectively restrained. This is because the difference between the mechanical input power and the electrical output power in the generator is decreased due to absorption of the real power by the limiting resistance of FCL. The load angle swing is also effectively restrained in case of “with TCBR”. In particular, the load angle becomes almost constant after the second wave. However, as TCBR starts to operate after the clearing of fault, the first wave of load angle swing is not restrained so much. Finally, in case of “with both devices of FCL and TCBR”, the load angle is nearly constant for the overall duration of simulation. From these responses, it is clear that the use of both devices of FCL and TCBR makes the system stable quickly more than the use of any of these devices.



(a) No devices



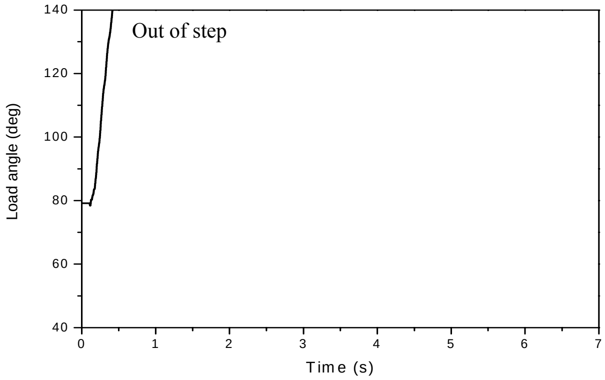
(b) With FCL and TCBR

Fig. 5 3-Phase Current Flowing Into Faulted Line.

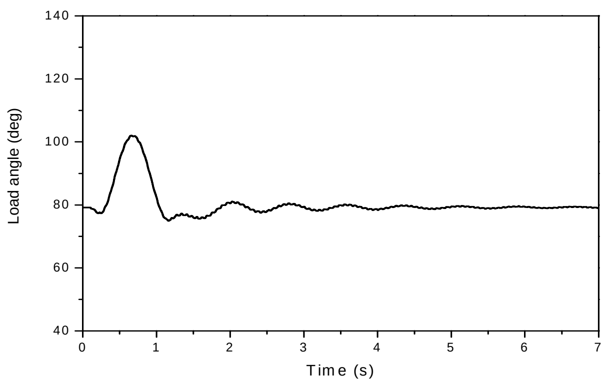
5.3 Suppression of Turbine Shaft Torsional Oscillations

In reality, a steam turbine-generator rotor has a very complex mechanical structure consisting of several predominant masses (such as rotors of turbine sections, generator rotor, couplings, and exciter rotor) connected by shafts of finite stiffness. Therefore, when the generator is perturbed, torsional oscillations occur between different sections of the turbine-generator rotor. The certain electrical system disturbance can significantly reduce the life expectancy of turbine shafts [7]. Therefore, sufficient damping is needed to reduce turbine shaft torsional oscillations.

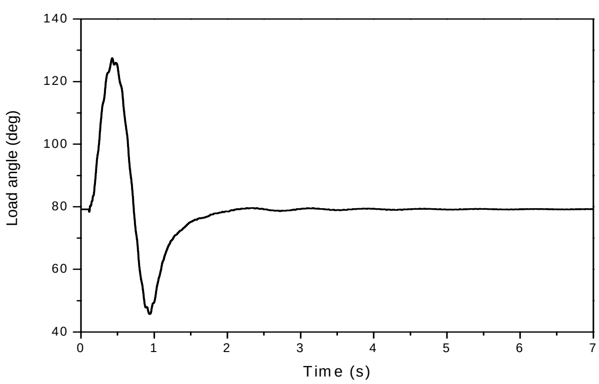
Fig. 7 shows the turbine shaft torque responses in each case. In case of “no devices”, as the generator becomes out of step, the torques of turbine shafts between each mass are also advancing towards the divergence. In cases of “with FCL” and “with FCL and TCBR”, the torque



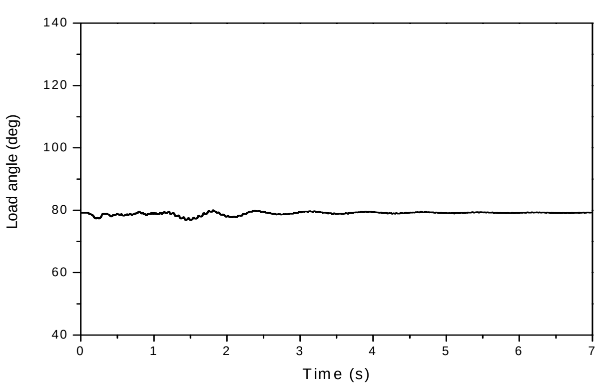
(a) No devices



(b) With FCL

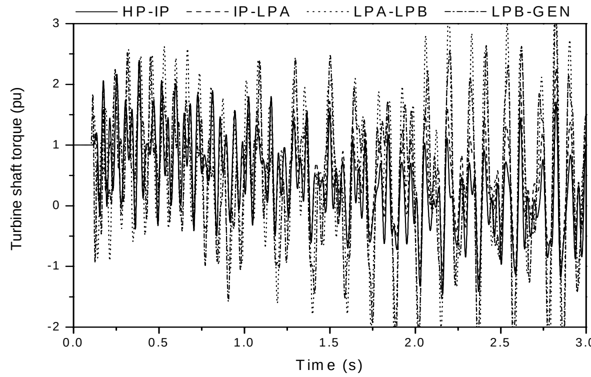


(c) With TCBR

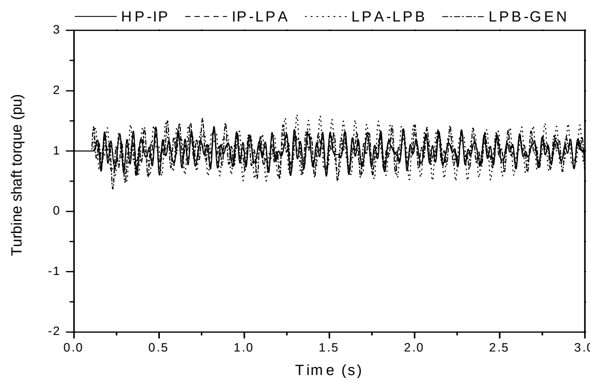


(d) With FCL and TCBR

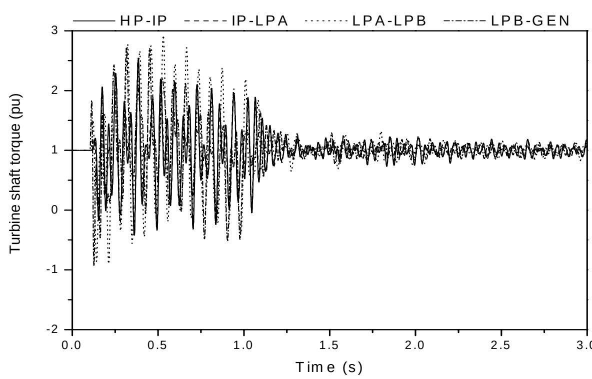
Fig. 6 Load Angle Responses.



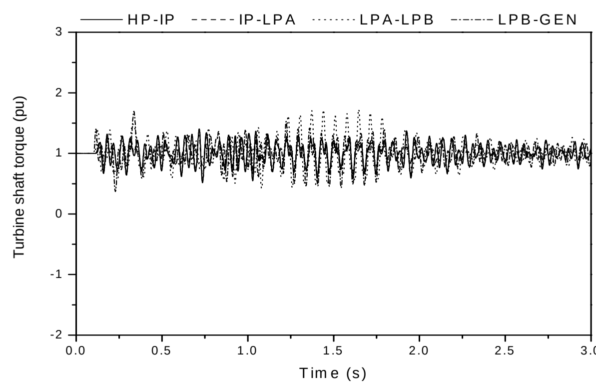
(a) No devices



(b) With FCL



(c) With TCBR



(d) With FCL and TCBR

Fig. 7 Turbine Shaft Torque Responses.

oscillations are effectively restrained. The torque oscillations in case of “with TCBR” are restrained slowly due to the late start of operation. However, the oscillations from about 1.2 sec are restrained very much. From these responses, it is clear that FCL and TCBR are effective devices for damping the turbine shaft torque oscillations.

5.4 Rotor Speed, Firing-angle and Dissipated Power in TCBR

Figs. 8-10 show the speed deviation in generator, the firing-angle of the thyristor switch and the dissipated power in TCBR in case of “with FCL and TCBR” respectively. The firing-angle varies from 0 to 180 degrees according to the value of speed deviation. Namely, as shown in Figs 8-10, when the speed deviation is large, the firing-angle is a small value or 0 degree value, thus the dissipated power in TCBR increases. When the speed deviation is small, the firing-angle is a large value or 180 degrees, thus the dissipated power in TCBR decreases. In this way, as TCBR is operated dynamically and with flexibility, it can effectively enhance the power system transient stability.

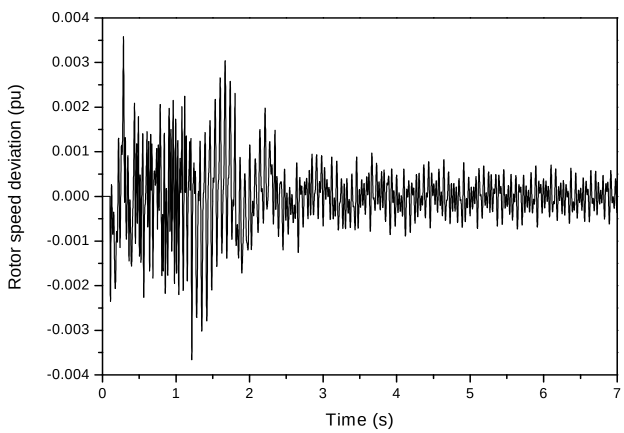


Fig. 8 Rotor Speed Deviation in Case of “With FCL and TCBR”.

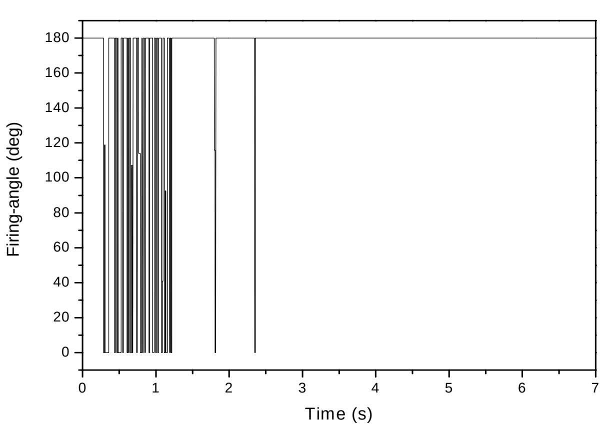


Fig. 9 Firing-angle Response in Case of “With FCL and TCBR”.

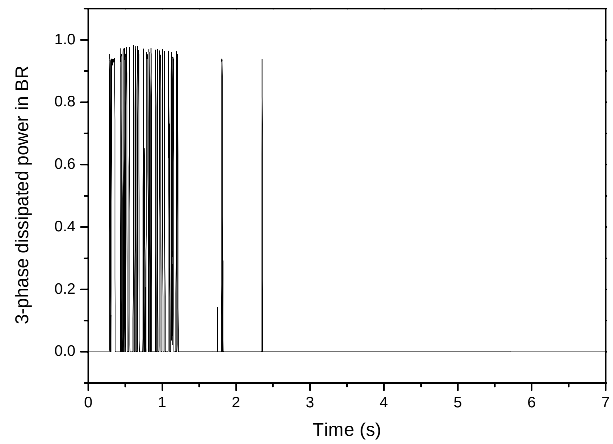


Fig. 10 3-Phase Dissipated Power in TCBR in Case of “With FCL and TCBR”.

6. Conclusion

In order to enhance the power system transient stability and damp the turbine shaft torsional oscillations, the use of both devices-fault current limiter and thyristor controlled braking resistor is proposed in this paper. If both devices operate at the same bus, the stabilization control scheme can be carried out continuously and with flexibility from the fault occurrence instance, thus the transient stability is enhanced effectively. The effectiveness of both devices is demonstrated by simulation considering three-lines-to-ground fault. Simulation results clearly indicate the significant enhancement of the transient stability and suppression of turbine shaft torsional oscillations.

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