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Oscillation Reduction Method of Shaft Torque Which is Associated with Instantaneous Voltage Drop for Private Generation System

A. Okazaki [*], G. Fujita [*], T. Nakano [**], K. Koyanagi [***], T. Funabashi [****], R. Yokoyama [****] and T. Kakinoki [****]

[*] Department of Electric Engineering Shibaura, Institute of Technology

[**] TEPCO System Corporation

[****] Meidensha Corporation

[****] Department of Electric Engineering Tokyo Metropolitan University

JAPAN

ABSTRACT

In this paper, the oscillation of terminal voltage, which are affected by fault of power system and so on, brings about the oscillation of the shaft torque of gas-turbine generator, therefore, the purpose of this study is to restrain the oscillation of the shaft torque with the shaft excitation control using torsional torque control device.

Since it is difficult to carry out this study using an actual non-utility generation equipment, numerical simulation is performed with a model of the non-utility generation equipment made in MATLAB/SIMULINK. The average torsional torque is used to evaluate the shaft torsional torque in case of on and off for the shaft torsional control.

1. INTRODUCTION

In recent years, for increase of power demand, reliable power supply must be maintained with limited energy resources, and increase of CO_2 is also getting worse. With these reasons, new generation systems come to being developed and used as generation system, which is in good efficiency and reduction of environment load. This new generation system consists of the distributed generation system, which is wind power generation, solar power generation, fuel cell and so on, and small or medium scale cogeneration system (CGS) which are available for gas-engine or gas-turbine.

CGS is suitable for building which uses a large of electric and heat such as hospital, hotel, and department and is suitable for power supply and heat source of a large-scale building which are equipped with a non-utility generation equipment because of black out. The feature of this system is that the efficiency of total energy is high, the consume of fuel is reduced, and that is useful for emergency management because of having power supply for emergencies. A drawback of this system is that the generation cost depends on utility rate of heat. If heat demand is not so large, the total energy efficiency remarkably decreases, and the generation cost increases.

The advantage of gas-turbine generation equipment is that the weight is not so heavy, compact, number of parts is relatively small. The disadvantage is that inertia moment is large due to the high speed rotation, and system disturbance of the instantaneous power failure or the instantaneous voltage drops causes to transitent shaft torsional torque. Turbine-generator shaft systems are designed to endure generator short-circuit fault and asynchronous closing. However, for the interruption which is caused by the fault of power transmission line, it is necessary to consider for transient abnormal torsional oscillation which appears on turbine-generator shafts.

2. GAS-TURBINE GENERATOR MODEL

Fig.1 shows a gas-turbine generator model. The frequency range of the shaft torsional oscillation depends on interaction of between electrical system and mechanical system [6]. These model adopts seven masses model which is consisted of a turbine, joint A, joint B, a shear pin A, a shear pin B, a generator, an exciter. Further, this system is equipped with joint as reduction gear and provides shear pins in order to protect shaft from overload. This system is modeled on 7 masses and 1 shaft. The shaft rotation velocity between the shear pin B and the generator is used for the input of the devices.

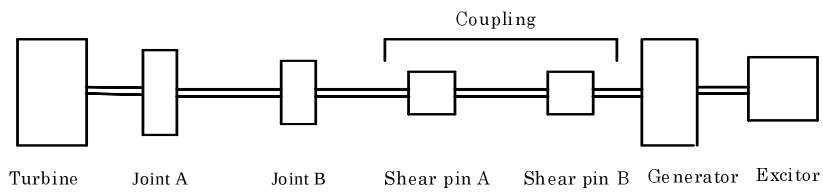

Fig.1 Gas-turbine generator model

Table 1 Mechanical constants of generator shaft

Mass	Inertia constant [s]	Spring constant [pu/rad]
1	2.122	274.1982
2	0.0811	1186.9
3	0.0233	500.6128
4	0.0044	264.2079
5	0.0044	28.3372
6	0.5688	21.6770
7	0.0087	

3. SHAFT TORSIONAL CONTROL DEVICE

In order to suppress the shaft torsional oscillation, though using torque components is desired in the excitation control, it is difficult to measure. Therefore, by extracting the torque phase from rotational speed components, reduction of the shaft torque is discussed. The input signal of shaft torsional control device is ω (shaft rotation velocity) and the output signal is added to AVR (automatic voltage regulator) as the shaft torsional auxiliary signal. Fig. 2 shows placement of this device. Direct current excitation is assumed for the excitation system model.

Fig. 3 shows the block diagram of shaft torsional control device. For the seven masses gas-turbine model, it is well known to exist the seven eigenvalue from state equation. However, two eigenvalue obtained from two masses model of turbine and generator, is affected by the shaft torsional oscillation. The shaft torque oscillation has short period (about 20 [Hz]) and long period (about 2 [Hz]) components, which is found from measured waveform or eigenvalue of the state equation. Filters are used to pass the components at two specified frequencies and these components uses for shaft torsional control respectively. Figs. 4 and 5 show the short and long period oscillations through the filter respectively. The phase delay can be compensated by this controller. The control gain may be turned according to the response. In order to reduce the shaft torsional oscillation for interruption of a fault point, this device is equipped with a limiter. If the limiter is used in this device, the upper bound is 0 and the lower bound is −10. In this paper, the compensation of time delay of AVR is considered only for the short period oscillation. This paper discusses two methods of the shaft torsional control. One is high order mode reduction control which control only high order oscillation using a limiter, another is both order mode reduction control which control short and long mode oscillation not using the limiter.

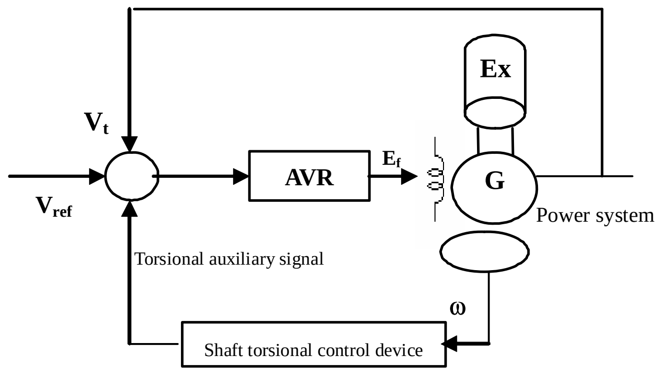

Fig. 2 Placement of shaft torsional oscillation

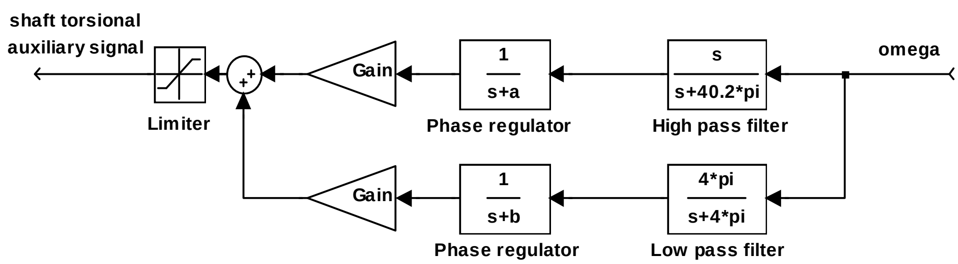

Fig. 3 Shaft torsional control device

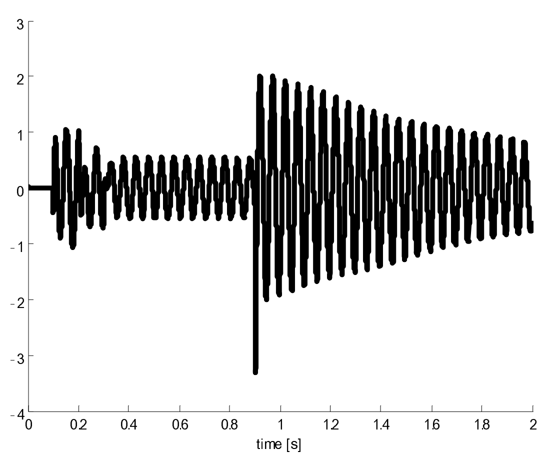

Fig. 4 High order mode oscillation

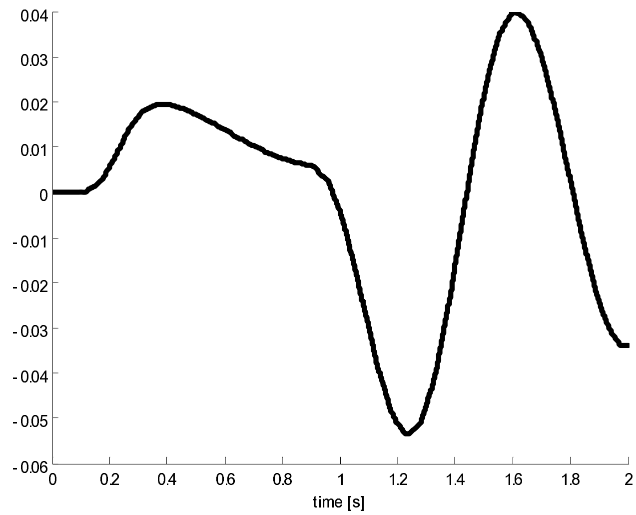

Fig. 5 Low order mode oscillation

4. PRIVATE GENERATION EQUIPMENT MODEL

4.1 Private Generation Equipment Model

Fig. 6 illustrates the private generation system in the case of single generator operation. In the system model, the non-utility generation equipment is linked to infinity bus by circuit breaker. For the discussion of system dynamics, a ground fault is assumed under the steady state operation. First, the ground fault occurs and the CB (circuit breaker) intercepts fault point instantaneously. In this case, the non-utility generation provides general load and importance load with power because of occurrence of ground fault. Since power supply of the non-utility generation is insufficient, the general load is separated in next step, followed by reclosing to restore the interconnection. The simulation flow is indicated in Table 2.

Table 2 Simulation flow

Step 0		Steady state operation
Step 1	0.1(s)	Ground fault
Step 2	0.2(s)	Interruption of fault point
Step 3	0.3(s)	Open of general load
Step4	0.9(s)	Reclosing

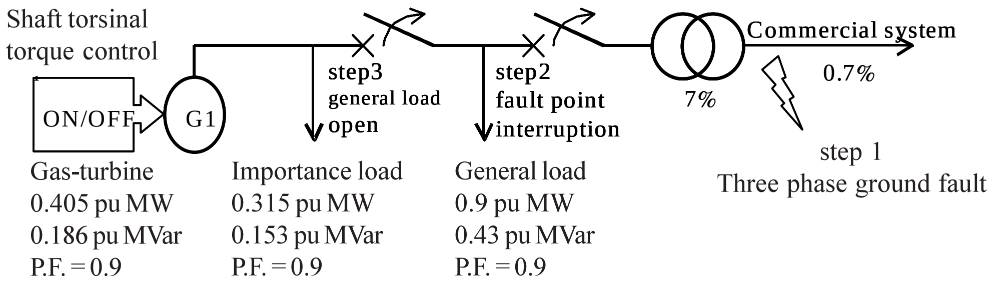

Fig. 6 Single generator operation

4.2 2-machine Parallel Operation

Fig. 7 shows the private generation system in the case of 2-machine parallel operation. Compared with single generator operation, only one of the generators is equipped with the shaft torsional control device. The simulation flow is similar to the flow in case of the signal generator operation.

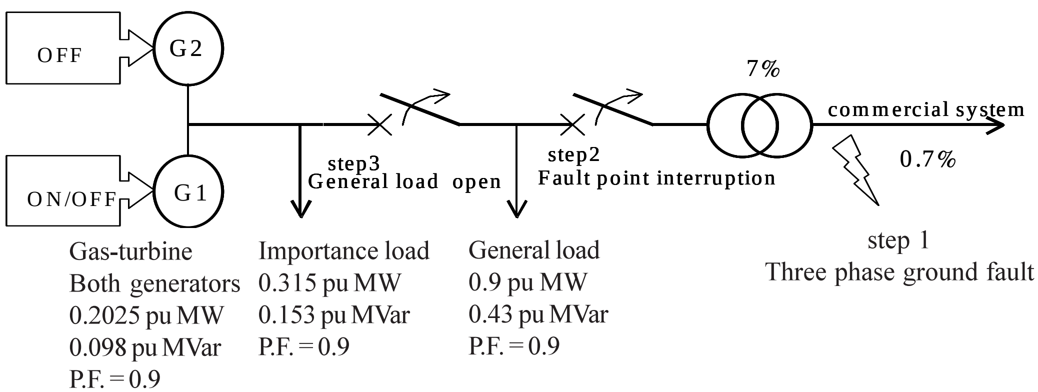

Fig. 7 2-machine parallel operation

5. DISCUSSIONS

5.1 Single Machine Operation

Fig. 8 shows shaft torque waveform and Fig. 9 shows terminal voltage waveform. For Fig. 6, the short period (about 20[Hz]) and long period (about 2[Hz]) component are overlapped each other in the waveform in case of no shaft torsional control. The shaft torsional oscillations before reclosing(before 0.9[s]) of short period component much larger than that of long period component. Therefore, in case of high order mode reduction control, it is noted that this oscillation is cancelled in about 0.5[s] in consideration of short period component. And the maximum value of the shaft torque oscillation for interruption of fault point is smaller than that of both order mode reduction control. After reclosing, the oscillation is effected by long and short period component, therefore in case of both order mode reduction control, the oscillation is cancelled in consideration of short and long period component. For terminal voltage, the maximum voltage of high order mode reduction control is smaller than that of no shaft torsional control, but the maximum of both order mode reduction control is larger than that of no shaft torsional control. Since the high order mode reduction control has the limiter, the maximum terminal voltage in interruption of fault point can be restrained.

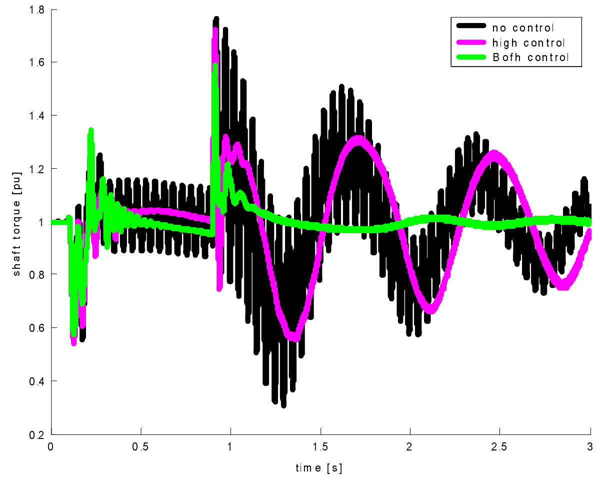

Fig. 8 Shaft torque waveform(Single generator)

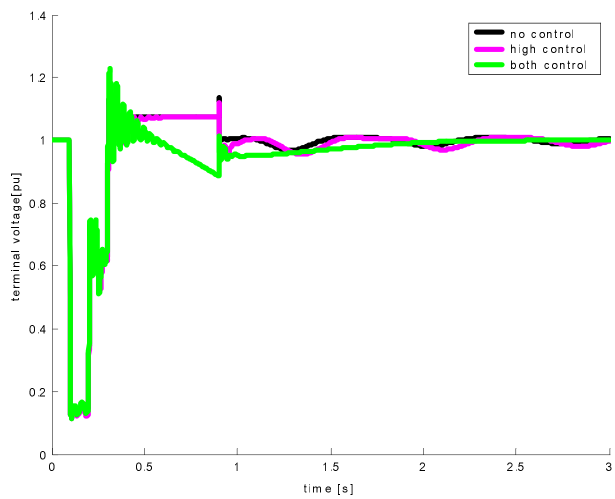

Fig. 9 Terminal voltage waveform(Single generator)

5.2 2-machine Parallel Operation

In 2-machine parallel operation, the shaft torque and terminal voltage waveforms are indicated in Figs.10-13. In this paper, the following discussion of the 2-machine parallel operation is devided into two sections. One is the discussion in G1 side using the shaft torsional control device. The other is the discussion in G2 side not using the shaft torsional control device.

5.2.1 Discussion of G1 side

Fig. 10 shows shaft torque waveform and Fig. 11 shows terminal voltage in G1 side using the shaft torsional control device. This result is nearly similar to result of single generator operation. For no shaft torsional control, the shaft torsional oscillation in interruption of the fault point is larger than this oscillation right after a fault.

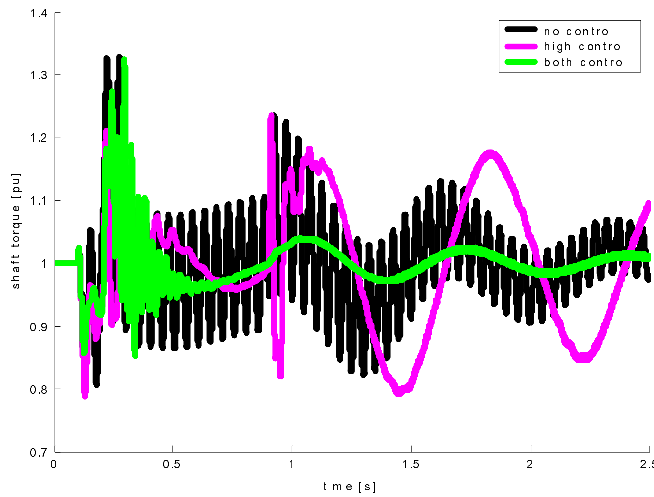

Fig.10 shaft torque waveform (Side of G1 device in two parallel generators)

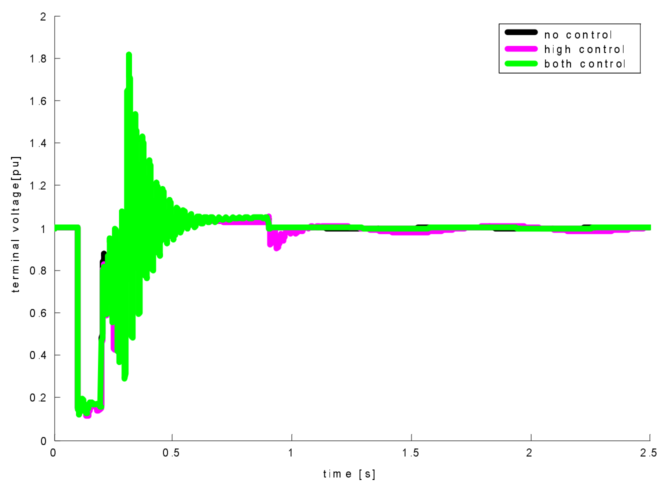

Fig.11 terminal voltage waveform (Side of G1 in two parallel generators)

5.2.2 Discussion of G2 side

Fig. 12 shows the shaft torque waveform and Fig.13 shows the terminal voltage waveform in G2 side not using the shaft torsional control device. It notes that these shaft torsional oscillation in short and both order mode reduction control are restrained because of effect in G1 side, using the shaft torsional device. And the result of these terminal voltage waveforms is the same as result of these waveforms in G1 side.

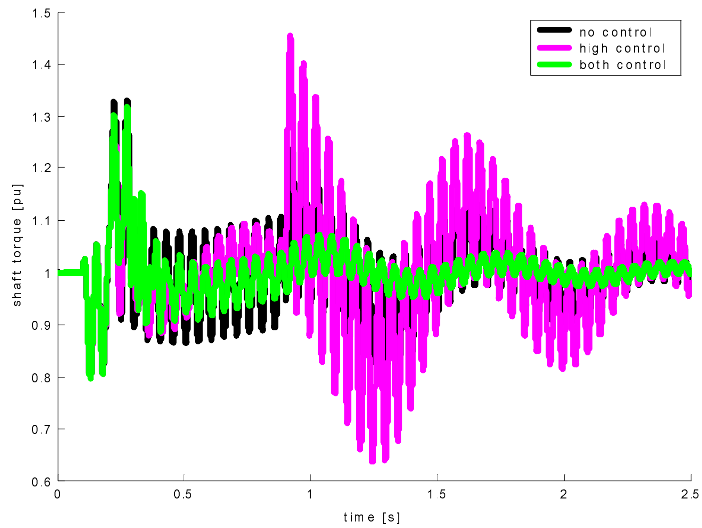

Fig. 12 Shaft torque waveform (Side of G2 in two parallel generators)

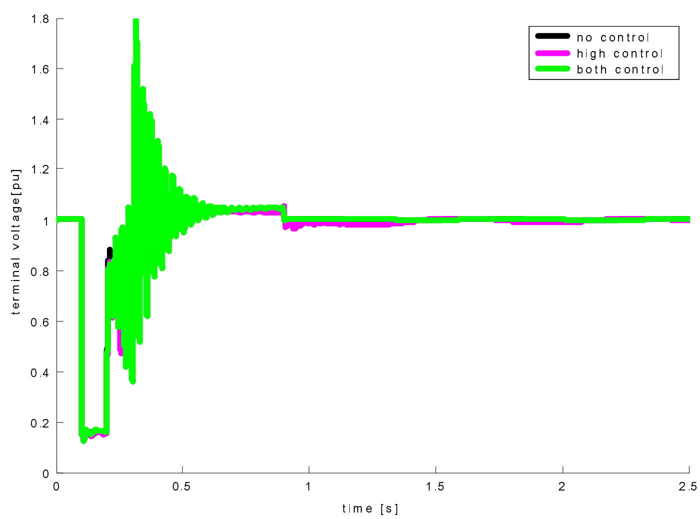

Fig. 13 Terminal voltage waveform (Side of the G2 in two parallel generators)

5.3 Evaluation Method of Shaft Torsional Control

In case of no control, high order mode reduction control, both order mode reduction control, it uses the average torsional torque to evaluate the shaft torsional control. In this paper, Eq. (1) is used to evaluate the average shaft torsional control.

$$S_{torque} = \frac{1}{T_{period}} \int |1 - torque| dt \qquad (1)$$

The value of the average torsional torque is that the S_{torque} derived from integration of torque deviation from normal operating point, derided by the duration. The division of range is indicated by Table 3. The vertical axis shows the value of the average torsional torque and the horizontal axis shows the time range respectively in Fig.13-15 of the average torsional torque.

Table 3 Time range of S_{torque} evaluation

No	Area[s]
1	Ground fault - Interruption of fault point (0.1[s] - 0.2[s])
2	Interruption of fault point - Open of general load (0.2[s] - 0.5[s])
3	Open of general load - Reclosing (0.5[s] - 0.9[s])
4	Reclosing - (0.9[s] - 2.5[s])

Fig.13 shows the average torsional torque in single machine operation. In these ranges of 1, 2, 3, the values by high and both order mode reduction control are smaller than that of no shaft torsional control. Fig.14 shows the average torsional torque in G1 side using the shaft torsional control device for 2-machine parallel operation. These results are nearly the same as that of single machine operation. In the range of No.2, the average torsional torque of high order mode reduction control is smaller than that of both order mode reduction control, because it is effect of the limiter. Fig.15 shows the average torsional torque in G2 side using no shaft torsional control device for 2-machine parallel operation. These shaft torques are restrained because of effect in G1 side using the shaft torsional control device.

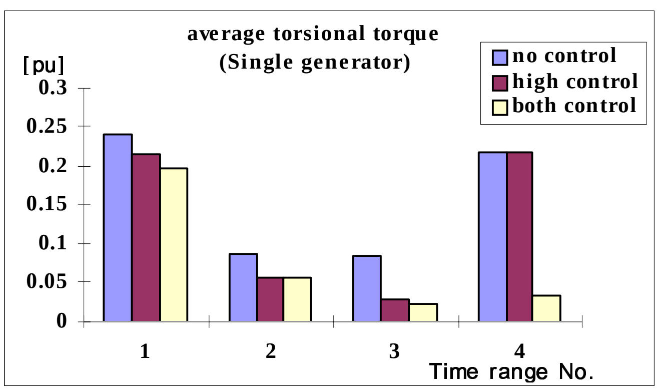

Fig.13 An average torsional torque (Single generator)

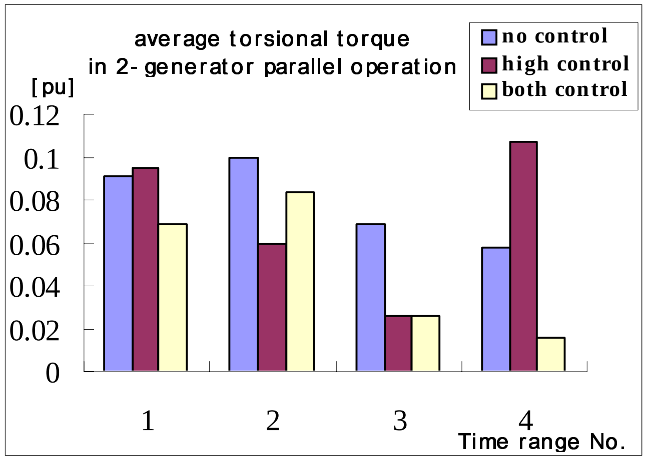

Fig.14 An average torsional torque (Side of G1 in two parallel generators)

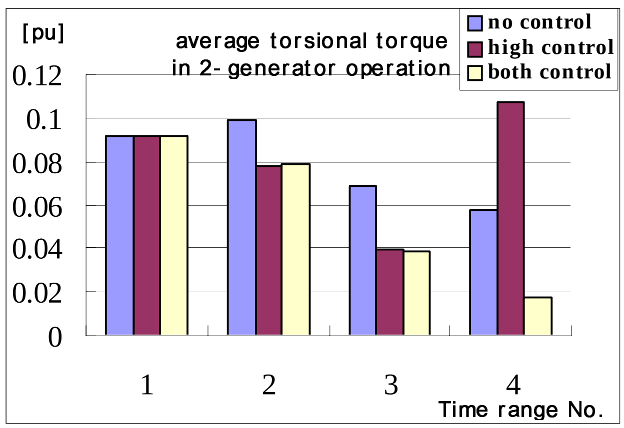

Fig.15 An average torsional torque (Side of G2 in two parallel generators)

6. CONCLUSIONS

In the result of these waveform and average torsional torque, the next draw a conclusion. Since most of the shaft torsional oscillation is the short period oscillation (about 20[Hz]) before reclosing, the shaft torsional control may restrain shaft torsional torque in high order mode reduction control. Moreover, the maximum value of the shaft torque right after interruption of a fault point may restrain to be available for the limiter. After reclosing, shaft torsional oscillation is reduced by both order mode reduction control, because the shaft torsional oscillation consists of short and long period oscillation.

In the future, this study focuses to find the optimum gain which minimized the maximum value of the shaft torque right after interruption of a fault and reclosing.

7. REFERENCES

[1] IEEE Torsional Issues Working Group. 1997. Fourth Supplement to a Bibliography for the Study of Subsynchronous Resonance Between Rotating Machines and Power Systems. *IEEE Transactions on Power Systems* 12(3).

[2] Walker, D. N.; Bowler, C. E. J.; and Jackson, R. L. 1975. Results of Subsynchronous Resonance at [3]Mohave. *IEEE Transactions on Power Apparatus and Systems* PAS-94(5).

[3] Abdennour, A. B.; Hamouda, R. M.; and Al-Ohaly, A. A. 2002. Countermeasures for Self-Excited Torsional Oscillations Using Reduced Order Robust Control Approach. *IEEE Transactions on Power Systems* 15(2).

[4] Brown, M. D. and Grande-Moran, C. 2000. Torsional System Parameter Identification of Turbine-Generator Sets. *IEEE Transactions on Energy Conversion* 12(4).

[5] Yu, Y.N. 1983. *Electric Power System Dynamics*. London: Academic Press Inc.

[6] Kundur, P. 1993. *Power System Stability and Control*: EPRI Press.

[7] Anderson, P.M. and Fouad, A.A. 1993. *Power System Control and Stability*: IEEE press.