The investigation of a shaft-torsional phenomenon objecting CGS

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Abstract - **Dispersed-generators system like a co-generation system (CGS) which is connected to the ratio interconnected to commercial system has increased. In this reason, system fault occurs at commercial system. For example, various electric faults, like the prevention of destroying shearpin accompanied a shaft-torsional torque phenomenon between gas turbine and generator, besides, instantaneous voltage drop has been highlighted. We investigated the explication and the suppression method of these phenomena, so that we report them [1,2].**

Keywords: Co-generation system (CGS), EMTP, Fault current limiter, Shaft-torsional, Shearpin

I. INTRODUCTION

In recent years, with increasing of energy demand, in the side of valid use of energy, customer's generation system like a CGS is spreading widely in industry, building, and public equipment like a hospital. And due to development of high information society, CGS also need the demand for quality as electric power supply source.

In general, it is because CGS use interconnection to commercial system. By reason of it, in the case that system faults occur at commercial system, source voltage drop temporarily (we call it instantaneous voltage drop), while the fault current is interrupted by breaker. And it damages demand load or interconnection to dispersed generation system. Fig.1 shows the customer's generation system and connected model system of commercial system.

In particular, in the case of gas turbine generation system, a shearpin is used between decelerator and generator in purpose of protection from overload to shaft of turbine, but sometimes destroys are found. By this reason, we estimate the condition of shaft-torsional torque of consumer's generation system connected with the power system.

As mentioned above, in this paper, we report on the following three headings.

i) The examination of shaft-torsional torque phenomenon of dispersed generator.
ii) The shaft-torsional torque suppression in the case that we apply a fault current limiter to the breaker of system connection as the protection equipment of shearpin destroy prevention.
iii) The effect of instantaneous voltage drop protection system of system-separated equipment as an object of model of interconnection to system.

For the purpose of inspecting about the effect, we simulated it by PC and used EMTP as an analysis tool.

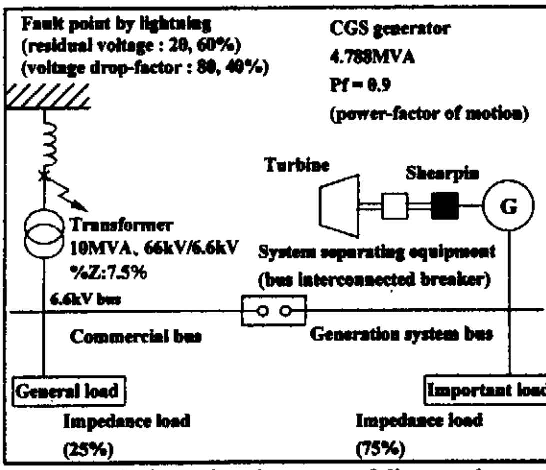


Fig.1. The shaft-torsional system of dispersed generation system and commercial system

II. THE VERIFICATION OF SHAFT-TORSIONAL TORQUE OF DISPERSED GENERATION SYSTEM AND SUPPRESSION METHOD

A. *The outline of shaft-torsional torque and eigenvalue method* [3]

A shaft-torsional torque causes phenomenon that machine on shaft among turbine generation systems connected to commercial system bring about mutual interference and the torque has any natural oscillation frequency. Especially, about dispersed generation system, in the case of three-phase short faults at the commercial system side, it becomes the factor of disturbance caused shaft-torsional torque so that it makes short current , and short torque appears electrically.

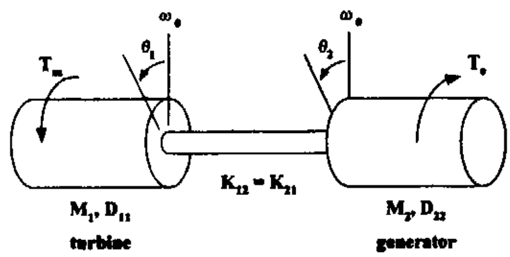
We assume that shaft-torsional torque joined in shearpin has two mass points with [turbine and decelerator] and generator, so in the case that we express it using equation of two shaft motions, it follows equation (1-a) and (1-b).

The equation of motion related to "turbine and decelerator" is following :

$$M_1\frac{d^2\theta_1}{dt^2}+D_{12}\frac{d}{dt}(\theta_1-\theta_2)+K_{12}(\theta_1-\theta_2)+D_{11}\frac{d\theta_1}{dt}=T_m \quad (1\text{-a})$$

The equation of motion related to "generator" is following :

$$M_2\frac{d^2\theta_2}{dt^2}+D_{21}\frac{d}{dt}(\theta_2-\theta_1)+K_{21}(\theta_2-\theta_1)+D_{22}\frac{d\theta_2}{dt}=T_e \qquad (1\text{-b})$$



M_1, M_2 : moment of inertia of turbine and generator
θ_1, θ_2 : location angle of each shaft
T_m : turbine machine torque
T_e : generator electric torque
D_{11}, D_{22} : damping coefficient
K_{12}, K_{21} : torsional stiffness

Fig.2. Shaft model of turbine generator.

At the base of equation (1), it can be transformed into the type of the system state equation (2). State variable vector x is following.

$x = [\theta_1(t), \theta_2(t), \dot{\theta}_1(t), \dot{\theta}_2(t)]$ where,

$\theta_1(t)$: potential angle of "turbine and decelerator" shaft
$\theta_2(t)$: potential angle of "generator" shaft
$\dot{\theta}_1(t)$: potential angular velocity of "turbine and decelerator" shaft
$\dot{\theta}_2(t)$: potential angular velocity of "generator" shaft

System state equation is given by :

$$\dot{x} = Ax + Bu \qquad (2)$$

$$A=\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -\frac{K_{12}}{M_1}\omega_0 & \frac{K_{12}}{M_1}\omega_0 & -\frac{(D_{11}+D_{12})}{M_1} & \frac{D_{12}}{M_1} \\ \frac{K_{21}}{M_2}\omega_0 & -\frac{K_{21}}{M_2}\omega_0 & \frac{D_{21}}{M_2} & -\frac{(D_{21}+D_{22})}{M_2} \end{bmatrix}$$

$$B=\begin{bmatrix} 0 & 0 \\ 0 & 0 \\ \frac{1}{M_1} & 0 \\ 0 & \frac{1}{M_2} \end{bmatrix} \qquad u=\begin{bmatrix} T_m \\ T_e \end{bmatrix}$$

A : transfer matrix (4×4)
B : control matrix (4×2)
u : operation matrix (2×1)
ω_0 : base radian frequency

We can get eigenvalue from following equation at the base of transformer matrix A :

$$|A - sI| = 0 \qquad (3)$$

By the equation (3), we have natural oscillation mode of shaft-torsional torque. However, in fact, we must calculate natural oscillation frequency from dynamic calculation in order to get various indefinite factor.

B. Shaft-torsional torque suppression method

In recent years, various type of high speed breakers have been proposed and are under development. We developed, for the purpose of suppression of instantaneous voltage drop, the high speed breaker with high speed response time about 100 times as fast as that of mechanical breaker (operating time is several cycles), so that it connects serially bus breaker used "the fault current limiter of composite semiconductor method combined vacuum value and GTO" showing Fig.3[4]. It allows current interruption in short time by this effect. Besides, we have, it suppresses short torque and shaft-torsional torque occurred in generation system electrically.

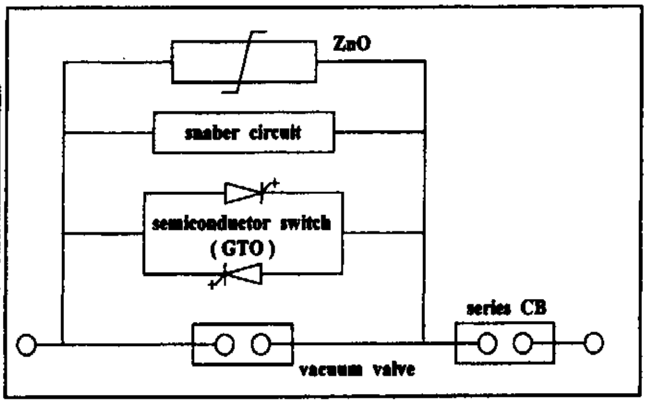


Fig.3. Basic configuration of the fault current limiter

III. THE INVESTIGATION OF EMTP

A. The suppression effect of shaft-torsional torque

We make input data for EMTP by using model system Fig.1, while it is fault condition that residual voltage of generation system bus is 20%,60% (in the neighborhood) at the commercial system side. We simulate torsional torque generating electric torque of generator and shaft when it is system-excepted conventional breaker and fault current limiter.

B. System condition for analysis

In the model connected system showing Fig.1, it's load is 100% of customer's generator rated capacity. We separated commercial system side and generation system side, the former is 25% of impedance load and the latter is 75%. Transformer was defined %Z as 7.5% at the base of 10MVA. The voltage of commercial system side was 66KV constant voltage source, short impedance was 0.4%Z (at the base of 10MVA). And, fault current limiter and breaker as a breaker for disconnection have been simplified with usual switch mode, generator Park's model and AVR control block modeled by TACS, we simulated them. We show Tab.1. generator parameters, Fig.4 the control block figure of AVR. We set GOV to be turbine output constant.

Name	Constant	Name	Constant
Rated capacity (MVA)	4.788	Xd (pu)	2.35
Rated output (MW)	3.83	Xq (pu)	2.69
Power-factor	0.9	Xd' (pu)	0.194
Rated voltage (kV)	6.6	Xd'' (pu)	0.167
Rotary number (rpm)	1800	Tdo' (sec)	2.6
Inertia constant (S)	3.339	Tdo'' (sec)	0.0215
		Ra	0.0063

Tab.1. generator parameters

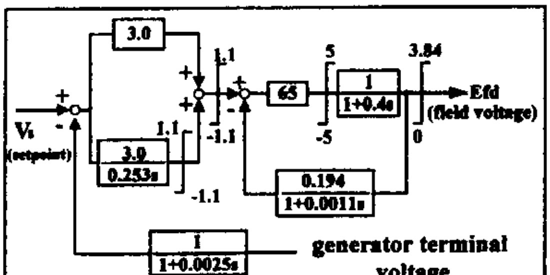


Fig.4. AVR block diagram

For the base of analysis condition we have mentioned, for the result of simulation wave form Fig.6 and Fig.7, we have the next three heading.

a) We could reproduce torsional torque occurred on shaft between turbine and generator by using EMTP.

b) We have the maximum peak value of shaft-torsional torque is 4 (pu) at conventional breaker, 1.5 (pu) at current limit system breaker and difference of torque suppress effect occurs.

c) From eigenvalue calculation by using equation (3), we could request the natural oscillation frequency of shaft-torsional torque was 36.7Hz. And regarding the natural oscillation frequency of shaft-torsional torque about 37Hz from the simulation wave form, we saw they were almost in accord.

As mentioned above, we can analyze the phenomenon of shaft-torsional torque system and the suppression effect.

C. The effect of system-separated system disconnecting model of interconnection to system

C.1 Connected model system

As Fig.1 shows, we connect bus interconnected breaker as system-separated equipment to a connected point of commercial system and dispersed-generators system. In the condition of connected-operating like this, in the case that short-circuit fault would occur in the commercial system and system power failure or instantaneous voltage drop, would occur until generation system and commercial one have system-separated by bus interconnected breaker, CGS dispersed generation system voltage-drop has a effect upon generation system and important load system. Depending on circumstances, there is a possibility that generator also stops, what is called, they fall together. Therefore, because these effects, are lowered we need to separate generation system and commercial system in high speed.

C.2 The effect of instantaneous voltage drop protection working

We show bus bar voltage wave form example Fig.8 and Fig.9 for the fault in the near place and in the far place when residual voltage is 20% and 60%. Showing these figures, conventional breaker is system-separated (interruption time of 5 cycles), so generation system bus voltage continues to drop on fault point. And after interruption, the voltage has just recovered only to some extent. Later, its voltage recovers to rated voltage with fluctuation, but, in this simulation, voltage fluctuation has also continued for about 1 second. On the other hand, the first wave in a moment of breaking is a little voltage, but the voltage has recovered to rating in a moment. If we adapt fault current limiter, as a system-separated equipment like this, even if the case that short-circuit fault occurs at commercial side, we can supply stabilized electric power to private important load.

IV. SUMMARY

i) We could verify the phenomenon of torsional torque occurred on generation system's shaft with system faults using eigenvalue method and EMTP.

ii) In the case that we apply fault current limiter to breaker as protection system of shearpin destroying prevention, the suppressing effect shaft-torsional torque is confirmed by simulation.

iii) Under connected operation with commercial system in the case that short-circuit fault occurs due to lightning etc. at commercial side, voltage drop of bus voltage at dispersed generation side would be suppressed in a moment because of system separation, so we could improve the confidence of supply to important load.

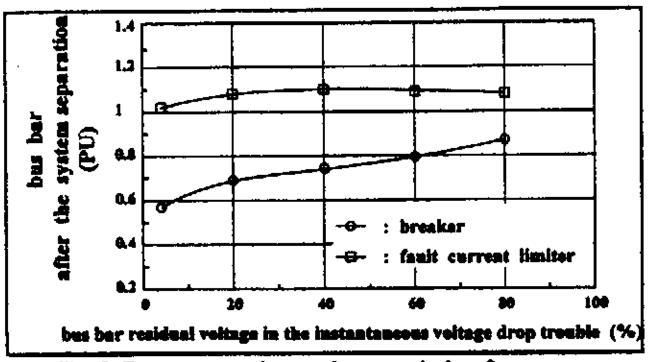


Fig.5. Recovery voltage characteristic after system separation to arbitrary residual voltage fault

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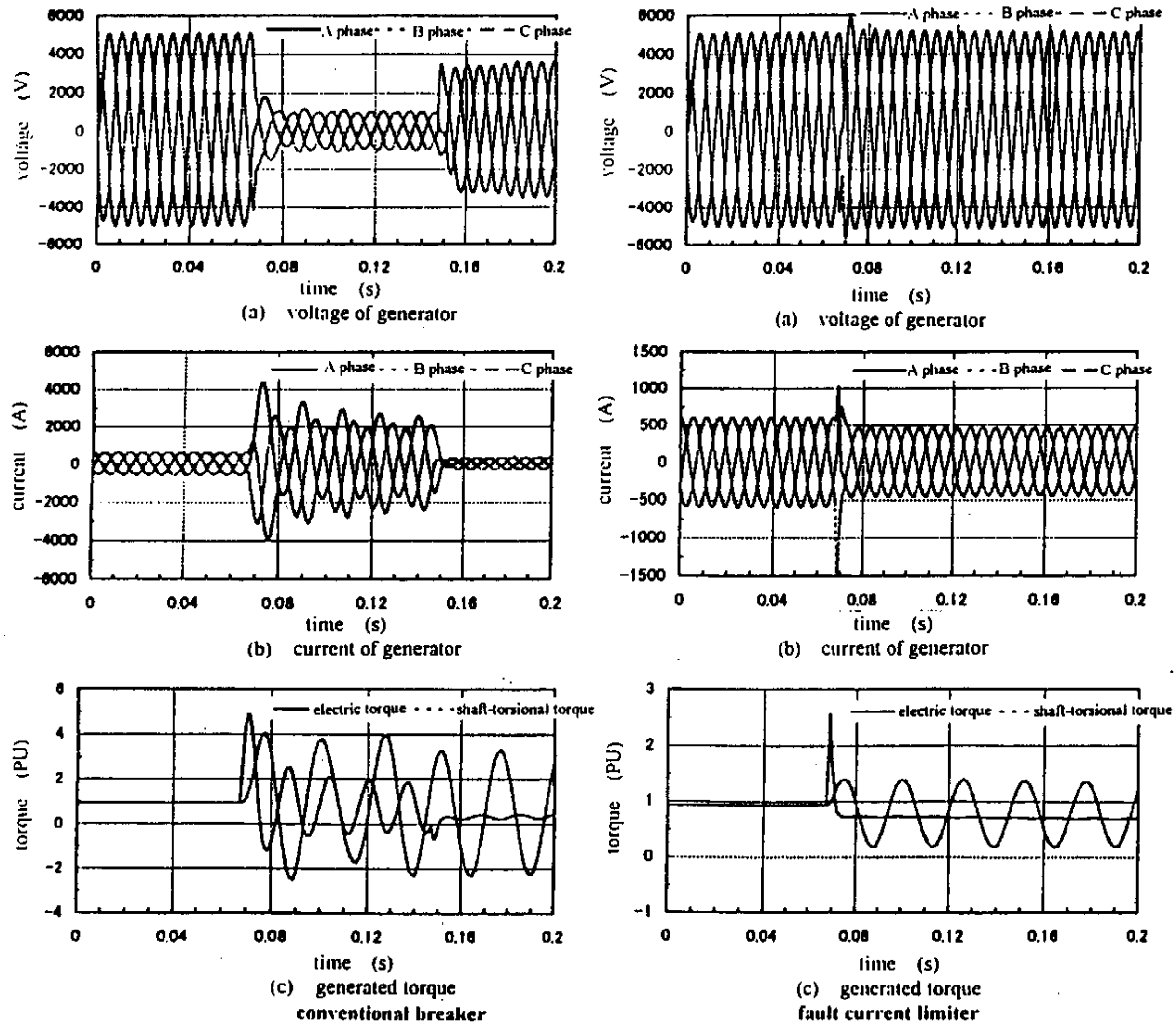

Fig.6. Bus voltage of residual voltage 20% (when fault occurs in the near place), bus voltage, bus current, and generated torque wave form

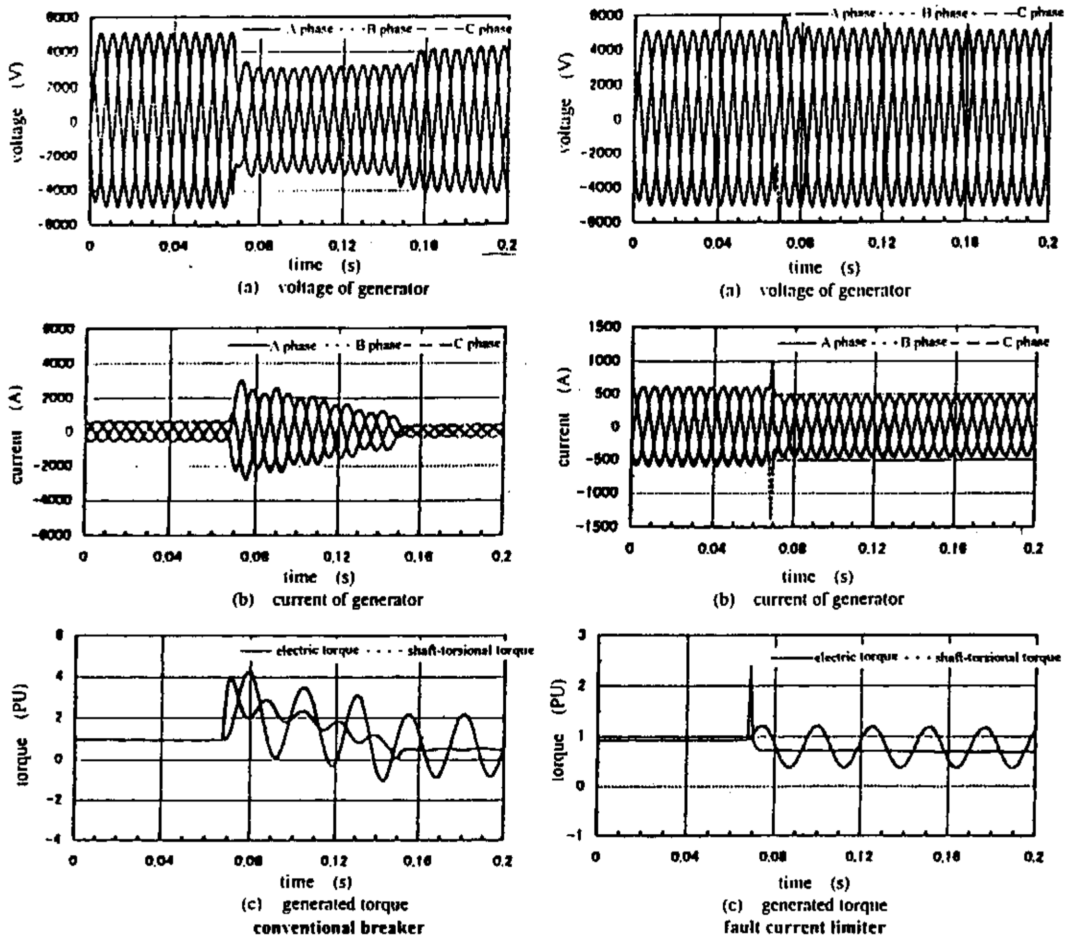

Fig.7. Bus voltage of residual voltage 60% (when fault occurs in the far place), bus voltage, bus current, and generated torque wave form

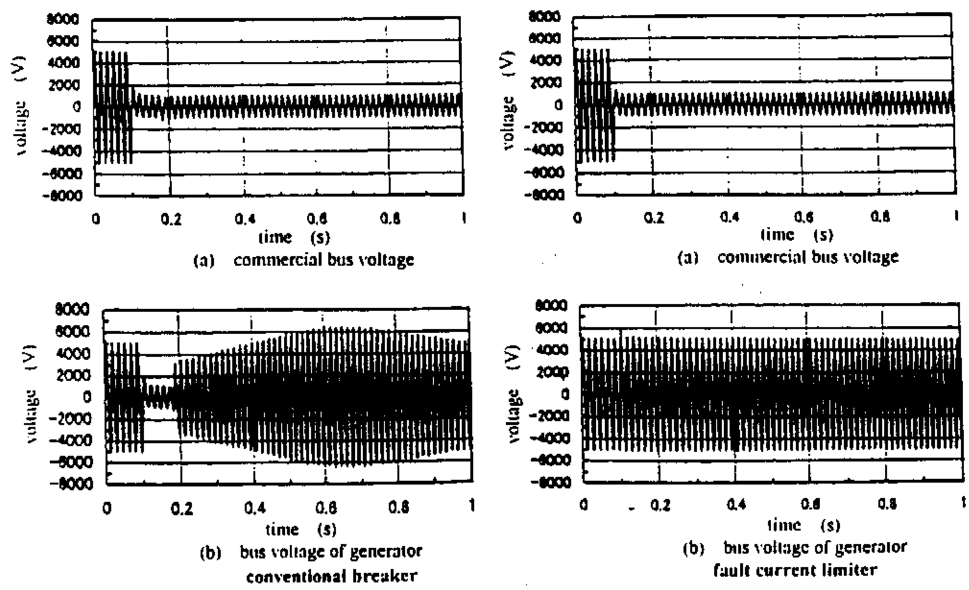

Fig.8. Bus voltage wave form of residual voltage 20% when fault occurs in the near place

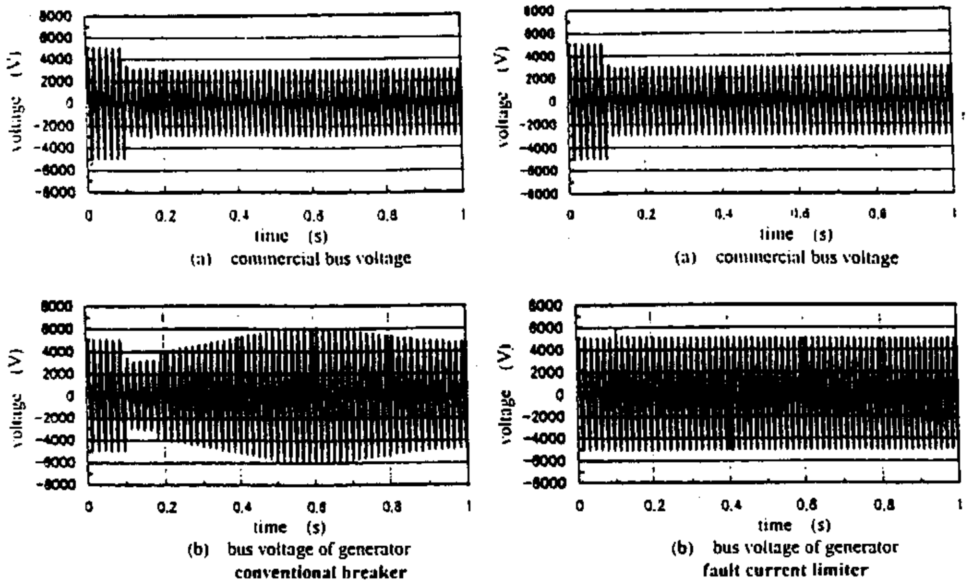

Fig.9. Bus voltage wave form of residual voltage 60% when fault occurs in the far place