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Full Length Research Paper

Behaviour of embedded generation during the voltage sags in distribution networks

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In recent years, using of small generators connected to distribution networks has been increaseingly preferred to supply local loads. They are called embedded or distributed generators because of they are connected to distribution networks. Both of them are generally used synonymously and interchangeable. In this study, dynamic performances of embedded generators are observed during and after the faults. The effects of symmetrical and unsymmetrical faults on the operation of the industrial plant included embedded generation units and also the stability of embedded generators is investigated for a medium voltage radial distribution network. Small-embedded generators are subjected to low frequency electromechanical oscillations that cause dynamic instability problems due to faults in utility side or inside. In this paper, these oscillations caused by balanced and unbalanced faults are simulated by using SIMPOW simulation software tool.

Key words: Voltage sags, embedded generators, distribution networks, power system stability.

INTRODUCTION

Traditionally, the electrical power are generated in large central power plants and transported to point of consumption via very high and/or high voltage interconnected transmission networks (Jenkins, 1996). Large hydro, fossil and nuclear power plants are some of central power plants. By installing large power plant, long transmission lines were constructed to transport electrical energy from power plant to load area and large interconnected electrical power networks were installed. However, in recent years a new power generation concept was developed and applied. This is called embedded generation.

By the addition of embedded generation plants to distribution networks, voltage profile of the network is improved and energy demand decreases from the utility network. Also, passive distribution networks are transformed into active networks after embedded units have been added to them (Ijumba et al., 1999; Milanovic and David, 2002).

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Embedded generation units improve voltage stability limits on large distribution networks (Milanovic and David, 2002; Jenkins and Strabac, 1997). In previous studies, protection of embedded generation plants against over current and islanding (Usta and Bayrak, 2001) effects of unsymmetrical faults on local generators (Alshamali and Fox, 2001), propagation of voltage sags on distribution networks (Radhakrishna et al., 2001) and influences of magnitude and duration voltage sags on shaft torque of small synchronous generators (Funabashi et al., 2000; Jenkins, 2000) were investigated.

In this study, dynamic performances of embedded generators are investigated. In studied system, there are two embedded plants connected to different buses. One of them includes two similar generators (connected to PCC bus) and its rated voltage is 11 kV, second one is smaller then first one, and includes only one generator connected to 6.3 kV bus (GEN_2 bus). Rated powers of each generator at 11 kV bus are 20 MVA, and the other is 16.6 MVA. In the simulations, unbalanced and balanced faults are applied to utility side and inside of Industrial plants and behaviour of all generators are observed for different fault clearing time.

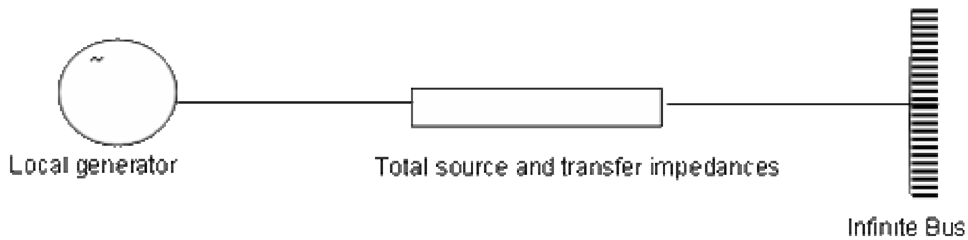

Figure 1. Grid connected embedded generation systems.

EMBEDDED GENERATORS

Since the mid 1970s there has been growing interest in the use of small and medium sized generation units operating in parallel with the local utility's electricity network. Several name have been used to describe these generators such as "private generators", "independent power producers (IPP)", "non-utility generators", "decentralized generation", "dispersed generation", "distributed generation", and "embedded generation". All of them are generally used synonymously and interchangeably.

Embedded generation units are connected within a distribution systems and do not have access to the transmission network. They could be connected to the distribution networks for one of following reasons: (Jenkins, 2000).

i. To sell of the generated energy obtained from hydraulic, biomass, solar and wind resources to the distributor.
ii. To serve as standby for the customer's supply systems.
iii. To supply of energy demand of industrial plants

Embedded generation systems are alternative to central power generation concepts because of its advantages. They are installed for small customers and industrial plants. The energy generated here can be cheaper than central power plants due to less cost of transmission lines and losses. These are connected to distribution networks so their voltage level is medium voltage and power range are between 5kW and 300 MW (Ackerman et al., 2001). Embedded generation plants are installed to provide only active power to the distribution networks. So theirs power factors are 1.0 or very close to 1.0. In stability analyses, synchronous generators in embedded plants can be represented by single machine-infinite bus power system one line diagram as shown in Figure 1.

A mathematical model for above system is given in equations 1-3 and Tables 1 - 4. Steady state active and reactive power equations are given in (4) and (5) for round rotor synchronous generators.

$$E_{FD} = R_{FD}.I_{FD} + \frac{1}{w_0}\frac{d}{dt}\Psi_{FD} \tag{1}$$

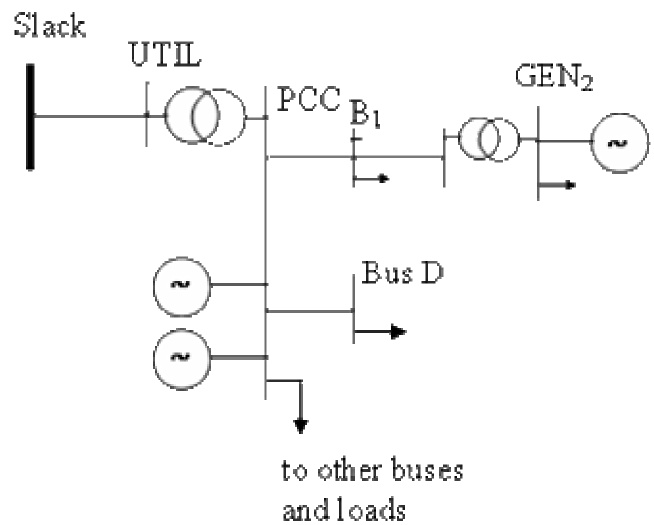

Figure 2. Sample distribution system.

$$\frac{dw}{dt} = \frac{1}{2H}[T_M - T_E - K_D.(w-1)] \tag{2}$$

Simulated distribution network

In computer simulations, distribution system in Figure 2 including two distributed generation plants is considered. One of the generation plants has two similar units. This plant is (called as big units) connected to bus PCC (point of common coupling) and its rated voltage is 11 kV. Second one (called as small unit) is connected to bus GEN and its rated voltage is 6.3 kV. Also the other characteristics belonging to all devices are given in appendices. Three cases are considered in this level. First, three phase to ground symmetrical faults are applied on following system. The other cases are respect- ively single phase to ground and phase phase to ground faults. In computer simulations, voltage variations and stability parameters (rotor angle and speed) belonging to both big and small units are observed and compared. Parameters of simulated system in Figure 2 are given in Tables 1 - 4.

Table 1. Line and cable parameters Parametreleri.

From	To	R (pu)	X(pu)
SLACK	UTIL	0.002	0.03
PCC	B1	0.0048	0.02
B1	B2	0.0024	0.01
PCC	D	0.0024	0.01

Table 2. Transformer parameters.

Primary	Secondary	S_N (MVA)	U_{N1} (KV)	U_{N2} (KV)	X (pu)
UTIL	PCC	50	34.5	11.7	0.04
B2	GEN	10	11.7	6.3	0.035

Table 3. Static loads and induction motor parameters.

Static loads		
Bus name	**P (MW)**	**Q (MVA)**
UTIL	20	15
B1	1.2	0.6
B2	0.6	0.35
Induction motor		
Bus name	**P (MW)**	**UN (kV)**
D	9	11

Table 4. Generator parameters.

	Gen1-Gen2	Gen3
U_N kV	11	6.3
S_N MVA	20	16.6
x_d pu	1.8	1.85
x_q pu	1.7	1.45
x'_d pu	0.3	0.3
x'_q pu	0.55	0.55
x''_d pu	0.25	0.25
x''_q pu	0.25	0.25
T'_{dO} sec	8	7

$$\frac{d\delta}{dt} = w_0(w-1) \tag{3}$$

$$P_E = \frac{E.V}{X_d}\mathrm{Sin}\delta \tag{4}$$

$$Q_E = \frac{E.V}{X_d}\mathrm{Cos}\delta - \frac{V^2}{X_d} \tag{5}$$

SIMULATION RESULTS OF CASES

Case 1: Three phase to ground symmetrical fault

i. At midpoint of distribution line between SLACK and UTIL buses (Case 1a). During the three phases to ground fault at distribution line, changes in terminal voltage, rotor and speed are shown in Figure 3. Response of small unit is represented by dotted line. Fault clearing time is 400 ms. Rotor angles increase to 150° in first swing. Oscillations are damped after voltage regulators start up.

ii. At PCC bus (Case 1b) occurred on the terminals of big units (PCC bus). As shown in Figure 4, rotor angle of big units reach to an unstable point and these generators are disconnected from the network. Small unit is also disconnected by its protection devices. It is effected the instability of big units.

iii. At Bus D (Case 1c): In this case, generators are not disconnected from the networks, but they are subject to low frequency oscilla-tions after the fault is cleared as shown in Figure 5.

iv. At Bus GEN (Case 1d): Small unit is unstable and disconnected from the networks, but big units are stable and they continue to feed the networks. Figure 6 illustrates this case.

Case 2: Single phase to ground unsymmetrical fault

i. At midpoint of distribution line between SLACK and UTIL buses (Case 2a)

Fault point is more close to big units than small unit. So terminal voltages of small unit do not change. But big units were more affected. While faulted bus voltage decreases, other buses increase. Also oscillations in speed and rotor angle were occurred. These oscillations have small magnitude. Results are shown in Figure 7.

ii. At Bus D (Case 2b)

In this case, an interruption occurred at A-phase (faulted phase) of PCC bus. Also small oscillations are occurred. Figure 8 illustrates the results.

Case 3: Two phase to ground unsymmetrical fault (Case3)

i. At midpoint of distribution line between SLACK and UTIL buses (Case3a)

Oscillations are small in both units. Magnitude of faulted phase voltages (A and B) decrease. Results are shown in Figure 9.

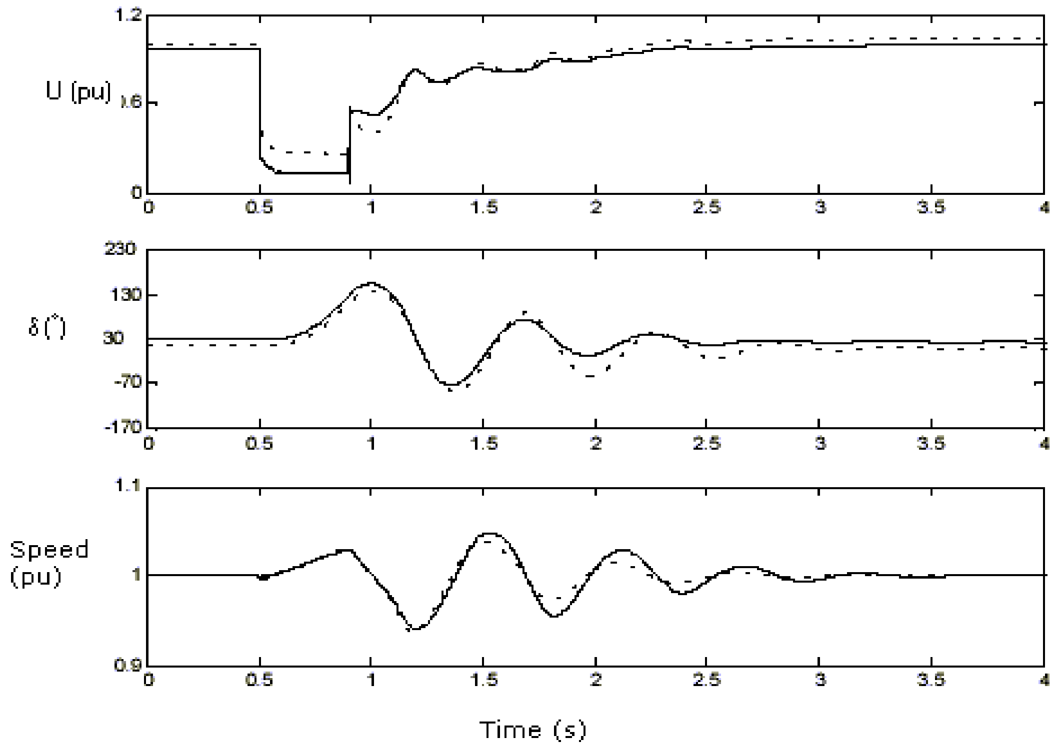

Figure 3. Responses of embedded generators for case 1a, dotted: small unit, solid: big units.

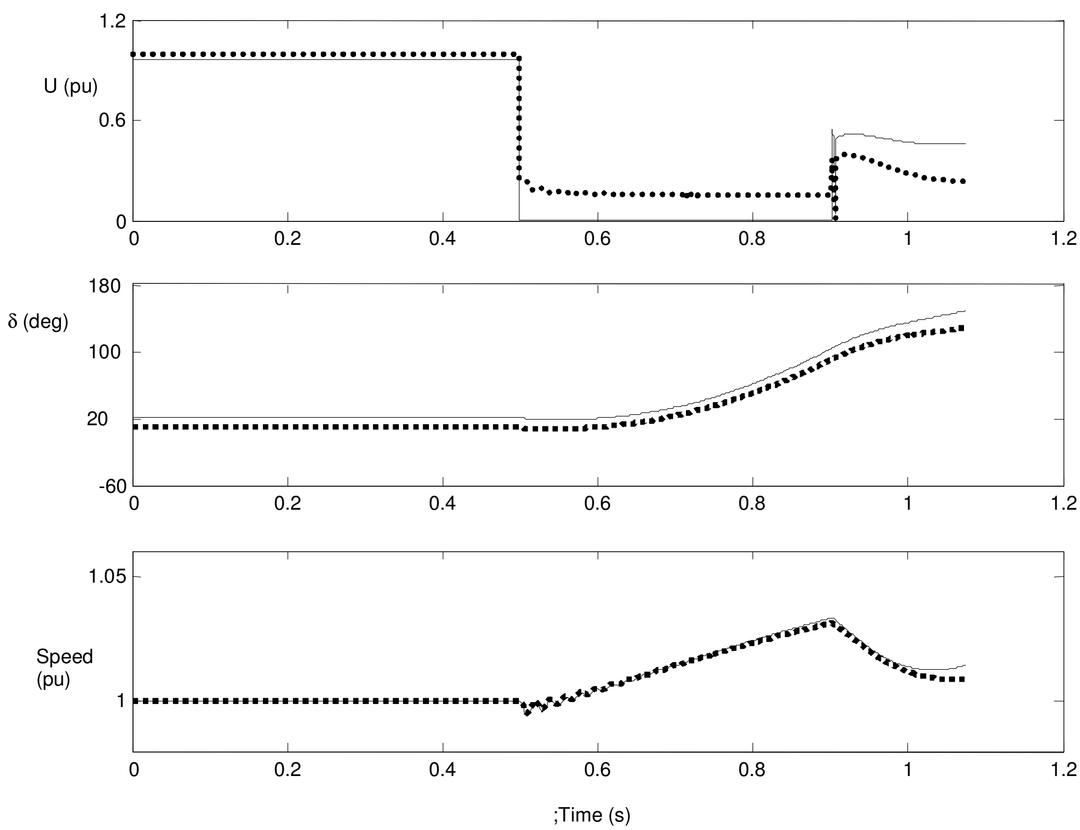

Figure 4. Responses of embedded generators for case 1b, dotted: small unit, solid: big units.

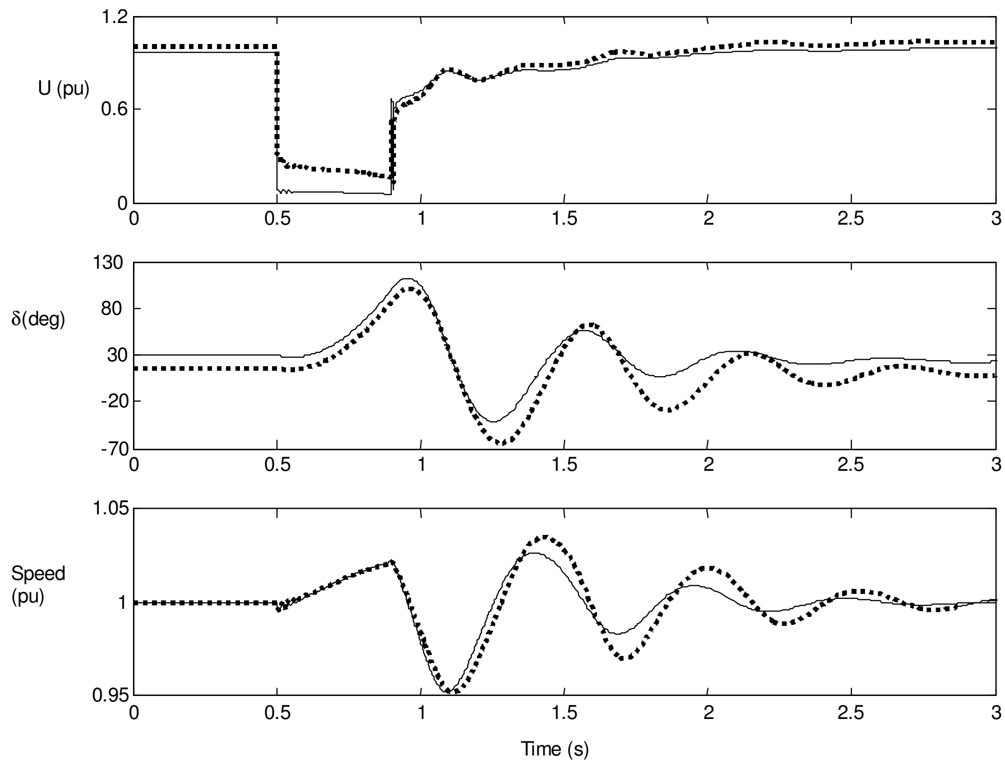

Figure 5. Responses of embedded generators for case 1c, dotted: small unit, solid: big units.

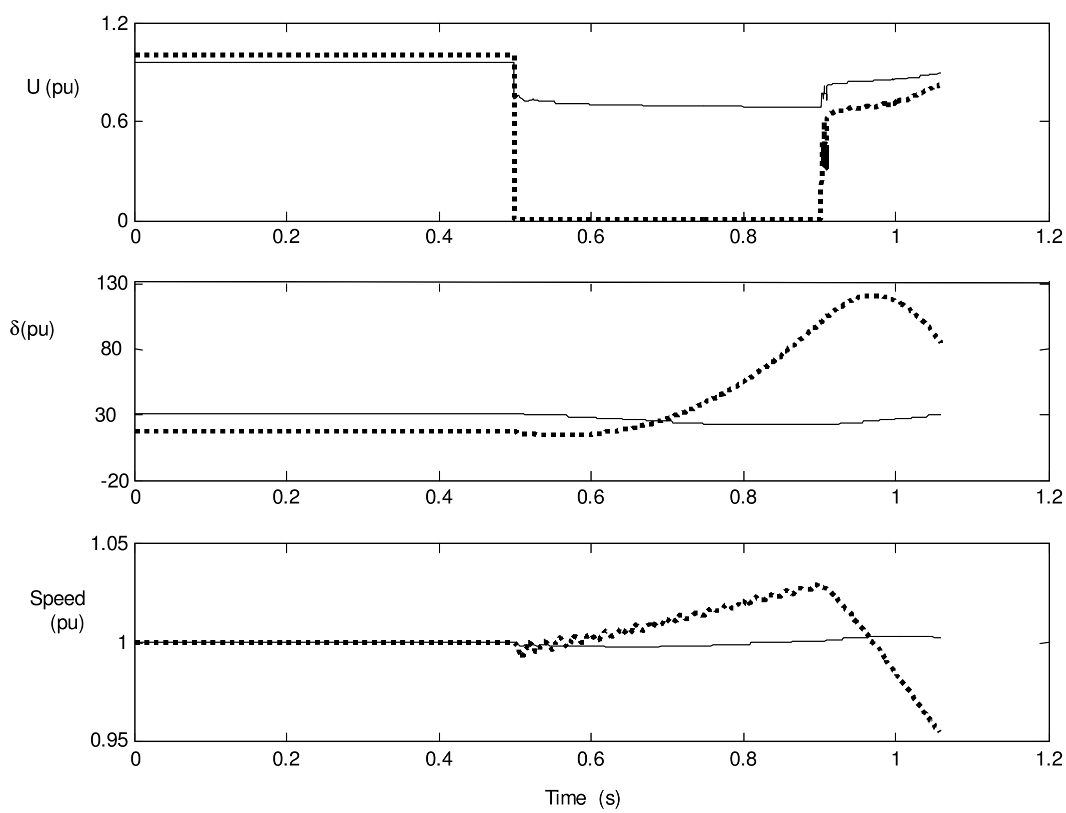

Figure 6. Responses of embedded generators for case 1d, dotted: small unit, solid: big units.

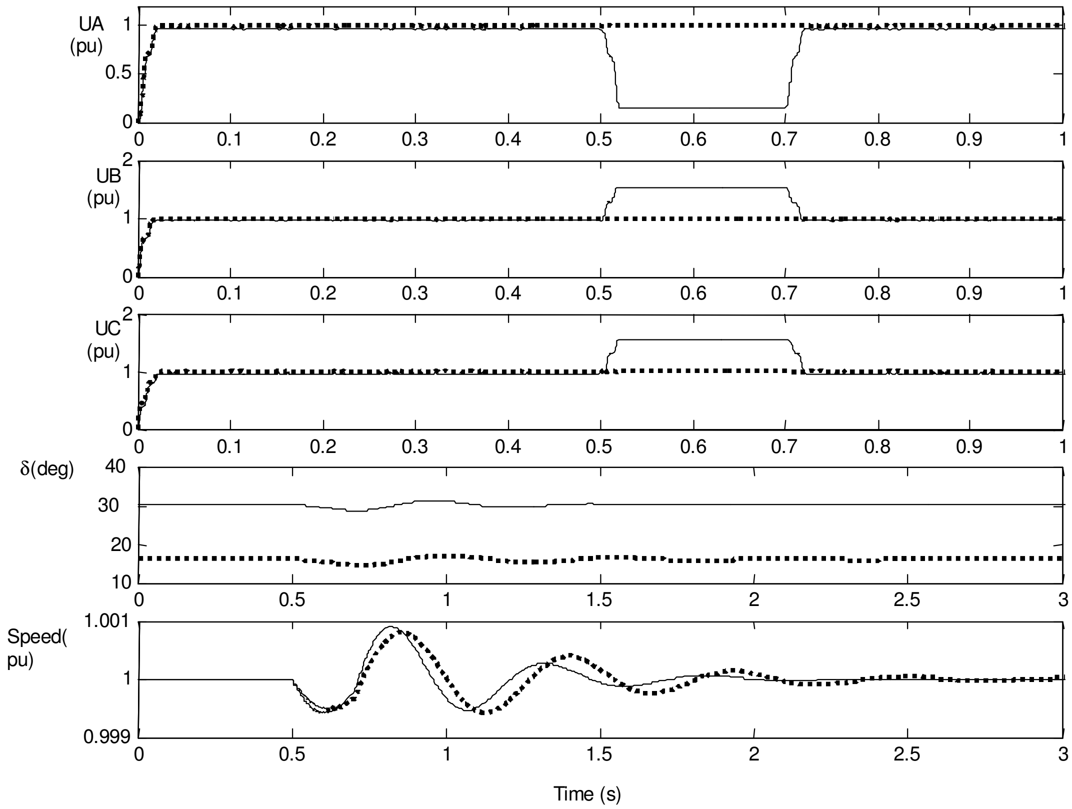

Figure 7. Responses of embedded generators for case 2a, dotted: small unit, solid: big units.

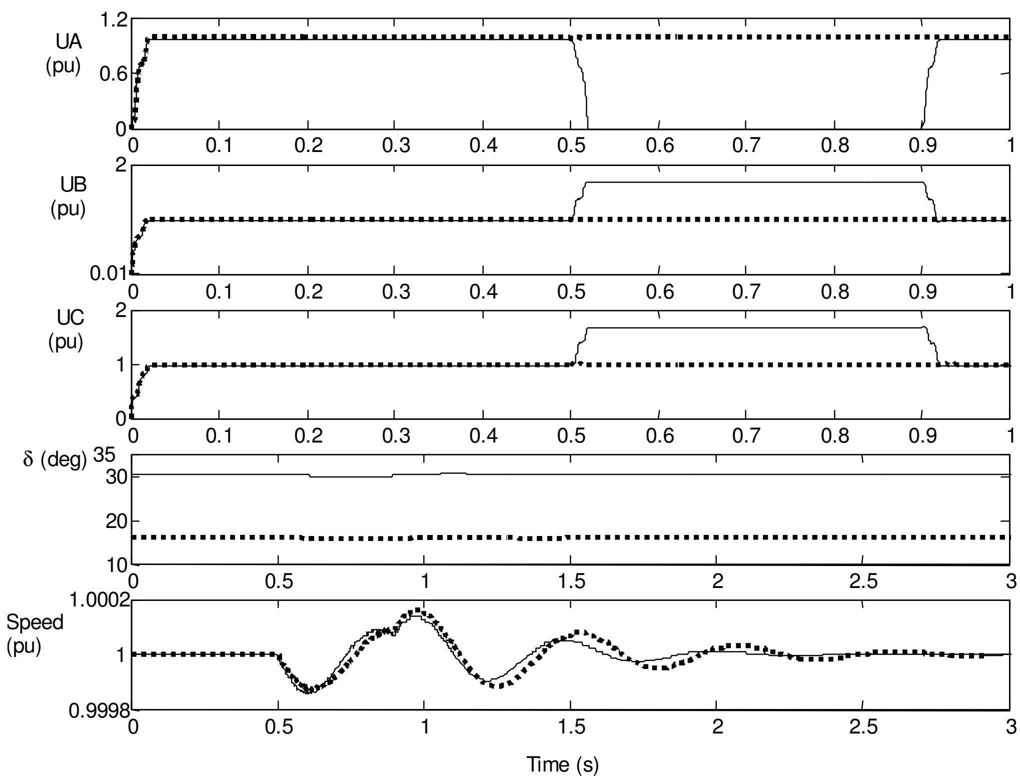

Figure 8. Responses of embedded generators for case 2b, dotted: small unit, solid: big units.

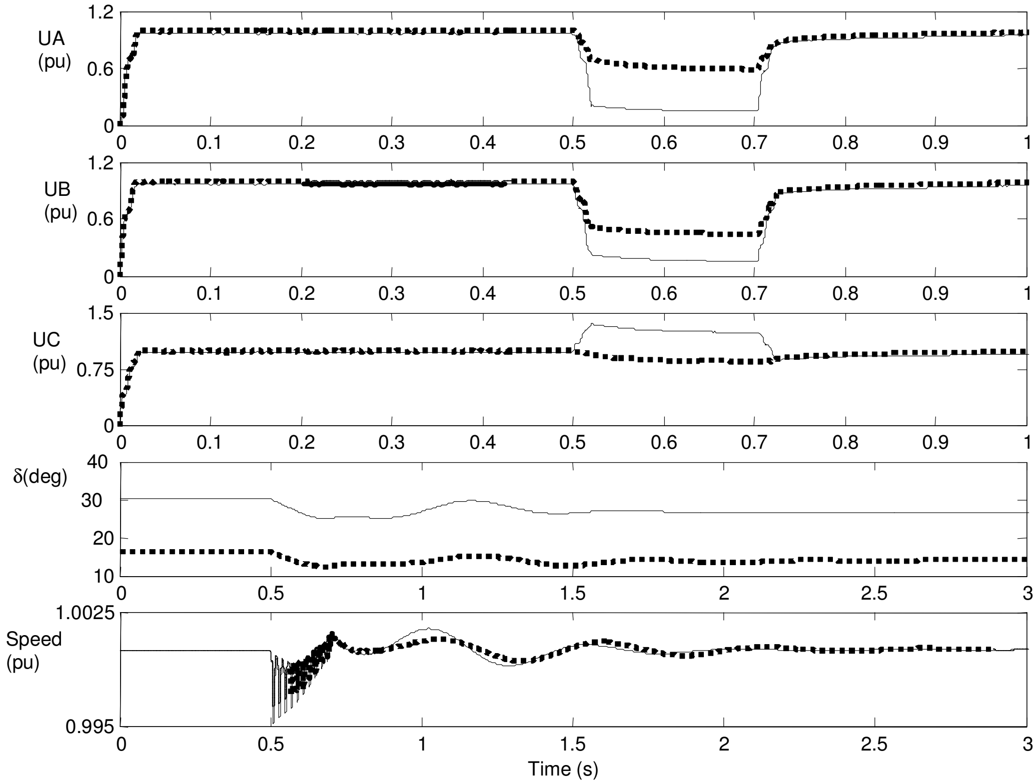

Figure 9. Responses of embedded generators for case 3a, dotted: small unit, solid: big units.

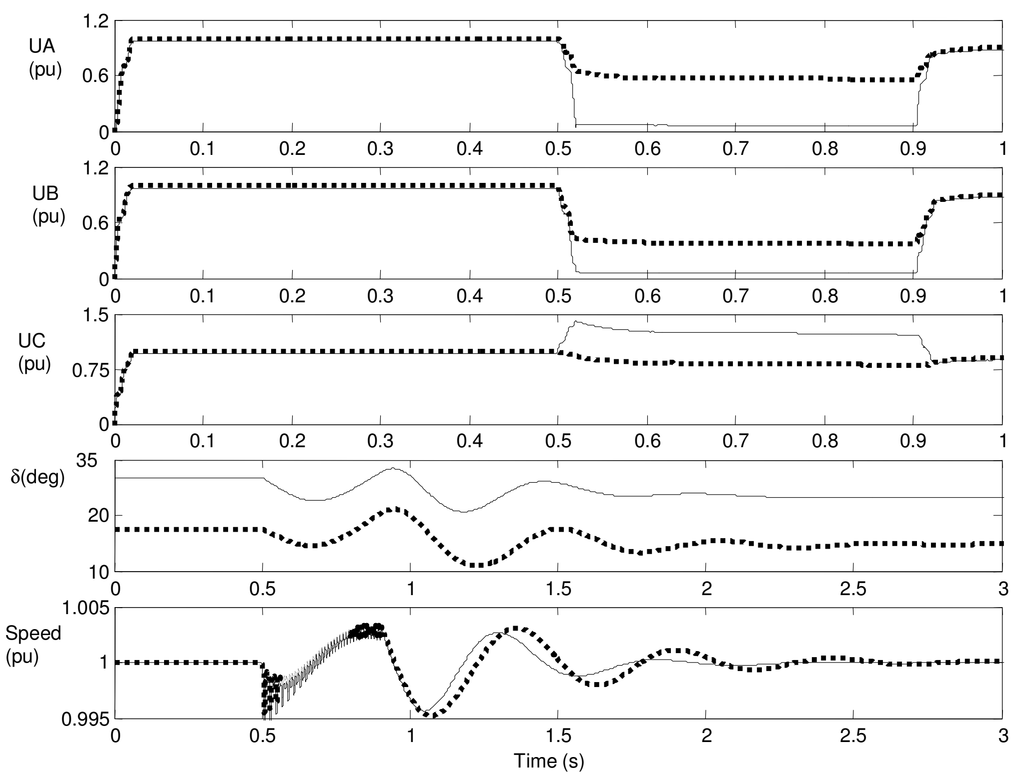

Figure 10. Responses of embedded generators for case 3b, dotted: small unit, solid: big units.

ii. At Bus D (Case 3b)

Fault location is closer than case 3(i), so magnitude of oscillation in rotor angle and speed are more than previous case. Results are shown in Figure 10.

CONCLUSIONS

In three phases to ground fault that is worst case, voltage is zero or very close to zero. In near faults (Figure 4), generators are isolated from the network. When the big units are disconnected, small unit (at Bus GEN) affects this condition. However, big units are not unstable when small unit goes to instability as shown in Figure 5.

In unsymmetrical faults (cases 2 and 3), generation units are not unstable but they are subjected to low frequency oscillations in theirs speeds and rotor angles. Magnitudes of these oscillations are smaller than case 1. While voltage sags occur in faulted buses, swells in voltage occur in non-faulted buses.

This study presents the behaviour of embedded generation units during the symmetrical and unsymmetrical faults in distribution networks. Industrial power networks include embedded generation plants, dynamic stability of generators have an important role in performance and quality of distribution networks. Stability of these units depends on fault location (remote and near fault), behaviour of other generation units, fault clearing time and fault type.

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