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Analysis of the System Impact of Distributed Generation using EMTP

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Abstract - With the advent of distributed generation, power systems in general are impacted in regards to stability and power quality. Distributed generation has positive impacts on system restoration following a fault, higher reliability, and mitigation of effect due to voltage sag. However, distributed generation also has negative impacts on the decrease of reliability such as changes of protective device setting and mal-operation.

Because bulk power systems consist of various sources and loads, it is complicated to analyze power systems that have distributed generation. The types of distributed generation usually are classified as the rotating machinery system and the inverter-based system.

In this paper, distributed generation is designed as a synchronous generator, and the distribution system with its distributed generation model is simulated using EMTP. In addition, this paper shows the simulation results according to the types of distributed generation

Keywords: Distribution system, Electric power systems, Fault, Generator, Protection

1. Introduction

Since the complexity of modern power systems is continually on the rise (longer lines, increased power transfer over existing lines due to the limitations imposed by environmental pressures, etc.), traditional analogue relaying is no longer able to cope with the performance requirements. Hence, the advantage of employing digital protection relays that are much better suited to coping with the modern-day protection problems, particularly in terms of speed and accuracy, is now of great focus [1]. Recently there has been considerable discussion connecting new generation to the distribution network and this is known as embedded, distributed or dispersed generation [2-3].

Such distributed generation has certain advantages and disadvantages. When a fault occurs in a power system, protective devices having malfunction and power system reliability decreases. Distributed generation in a distribution system has various effects such as network voltage changes and increase in fault levels.

Many researchers have studied distribution networks including distributed generation [4-6]. Particularly, J. V. Milanovic and R. Gnativ studied characteristics of voltage sags in a radial network with dynamic loads and embedded generator, and A. Girgis and S. Brahma studied the effects of distributed generation on protective device coordination.

In this paper, the distribution system with distributed generator is simulated for various system conditions in order to analyze and understand system impact of the distributed generation with particular reference to protection strategies. So, a model of the distribution system and distributed generation is designed as a synchronous generator, and simulated using EMTP. In this paper, simulation results are represented and impacts of distributed generation are analyzed.

2. Distributed Generation

Distributed generation was investigated by working groups, CIGRE (The International Conference on Large High Voltage Electric Systems) and CIRED (The International Conference on Electricity Distribution Networks). Distributed generation consists of synchronous or induction generators, or power electronic devices. They have some common attributes as follows [2-3].

(1) Not centrally planned
(2) Not centrally dispatched
(3) Normally smaller than 50-100MW
(4) Usually connected to the distribution system

The CIRED survey and the CIGRE report represented reasons for encouraging distributed generation. Some of these are listed below [2].

(1) Reduction in gaseous emissions
(2) Energy efficiency or rational use of energy
(3) Deregulation or competition policy
(4) Diversification of energy sources
(5) Ease of finding sites for smaller generators

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Because environmental impact is a major factor in the consideration of the electrical power scheme, distributed generation is classified into combined heat and power generation and renewable energy resources such as wind power, micro-hydro, solar photovoltaic, landfill gas, etc. The different classifications of distributed generation are for types of generation, such as synchronous generator, induction generator or inverter-based system.

A distributed generator is connected to an electrical distribution network. The distributed generator is typically used to supply electric power for consumers, but sometimes electric power generated by the distributed generator flows reversely through the distributed network. As such, it is important to ensure that they will not degrade the quality of supply for the consumer. Fig. 1 shows power flow at the distribution network with distributed generation.

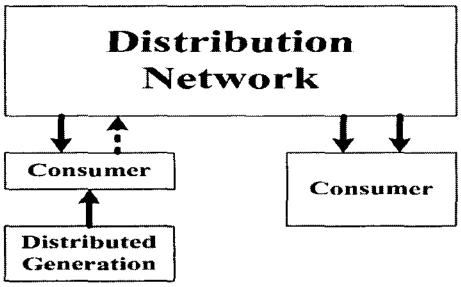

Fig. 1 Power flow at distribution network

In this paper, we design a model of synchronous generator using EMTP for simulation.

3. Simulation and Results

3.1 System model studied

The model system of a distribution network for simulation is shown in Fig. 2. The model system has 5 buses, 3 transformers, and 3 loads. Total simulation time is 1.5[sec], and sampling frequency is 3840[Hz].

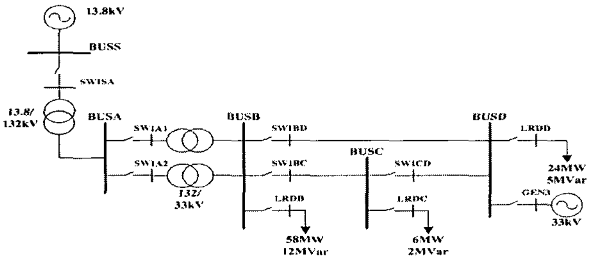

Fig. 2 System diagram for maximum load

The model system is introduced by reference [2] and is implemented by EMTP. BUSS has been chosen as the slack bus, so this generator will supply the active power required to balance the system. Therefore, BUSS is taken as the ideal source. Table 1 represents system parameters. Simulation was performed in 3 cases of system conditions.

(1) Maximum load, no distributed generation (DG)
(2) Maximum load, synchronous generator at BUSD
(3) Minimum load, synchronous generator at BUSD

And, a distributed generation under fault condition is simulated to analyze the system impacts. Table 2 presents fault types and fault locations. Fault starting time is 0.25[sec] and duration is 0.25[sec].

Table 1 System parameters for networks

From bus	To bus	Type	Resistance	Reactance
BUSS	BUSA	transformer	0.0	0.06670
BUSA	BUSB	transformer	0.00994	0.20880
BUSA	BUSB	transformer	0.00921	0.21700
BUSB	BUSC	line	0.04460	0.19170
BUSB	BUSD	line	0.21460	0.34290
BUSC	BUSD	line	0.23900	0.41630

Table 2 Fault types and locations

Fault type	Single line-to-ground (SLGF) 3-phase fault
Fault location	BUSA, BUSC, LineBD (line between BUSB and BUSD)

Load as shown in Fig. 2 is maximum load. Fig. 3 shows minimum load, where the loads have been set at 10% of the maximum loads.

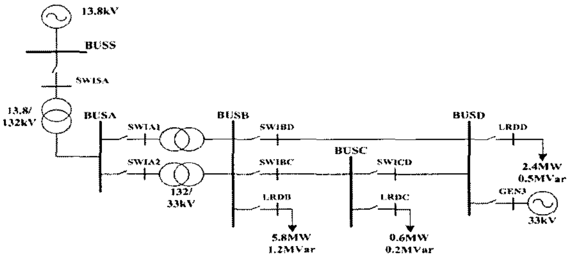

Fig. 3 System diagram for minimum load

3.2 No distributed generation system

At each bus and line, voltages and currents can be obtained, so RMS values are calculated. Per unit quantities are introduced, and baseMVA is 50MVA.

Table 3 lists voltages at each bus under normal condition Because voltage was sagged by loads and line impedances, a bus that was far from source has lower voltage than 1[pu] For example, voltage at bus BUSD is about 0.98[pu].

Table 3 Voltages at each bus under normal condition

Bus	BUSS	BUSA	BUSB	BUSC	BUSD
Voltage[pu]	1.0	1.0	0.994	0.991	0.982

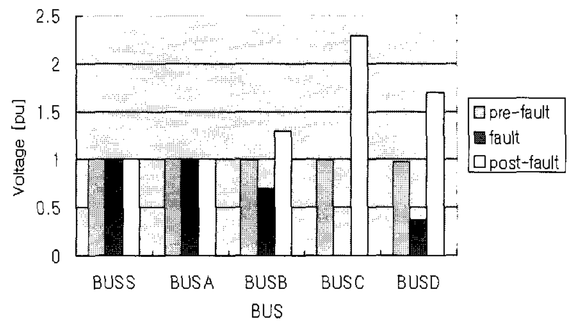

Fig. 4 Voltages at each bus under SLGF (BUSC)

Fig. 4 illustrates a bar graph for voltage at each bus under single line-to-ground fault at bus BUSC from each state. Here, post-fault voltage is not restored to pre-fault voltage, but rather it is increased to larger than pre-fault voltage. Fig. 5 shows currents waveforms through each switch.

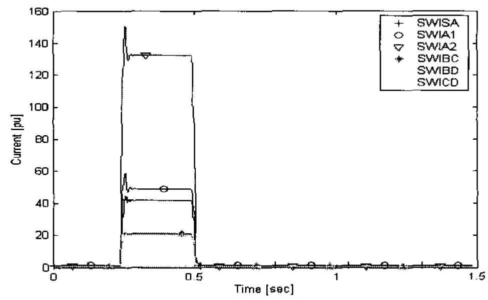

Fig. 5 Currents through each switch under SLGF (BUSC)

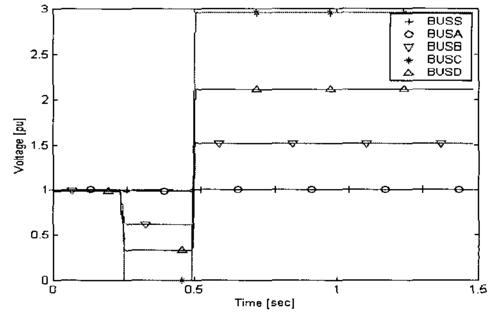

Fig. 6 Voltages at each bus under 3-phase fault

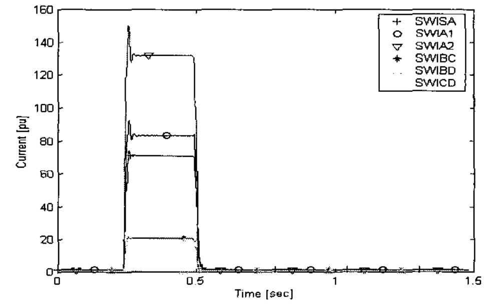

Fig. 7 Currents through each switch under 3-phase fault

Figs.6-7 show waveforms of voltage and current under 3-phase fault at bus BUSC, respectively.

As depicted in the figures, currents are magnified during fault and magnitude of voltage after a fault is in inverse proportion to the distance from the source. Figure 8 presents waveforms of voltage at bus BUSD under 3-phase fault condition. With this, we know that voltages of each phase lose balance.

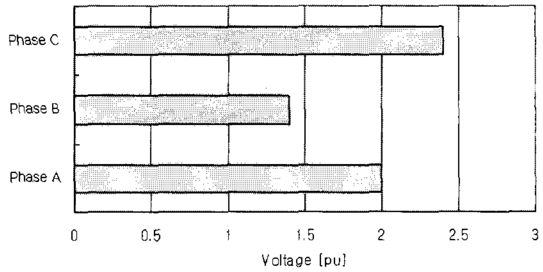

Fig. 8 Voltages at BUSD under 3-phase fault condition

3.3 Maximum load, synchronous generator

Figs. 9-10 show waveforms of voltages and currents under transient single line-to-ground fault at bus BUSC, respectively.

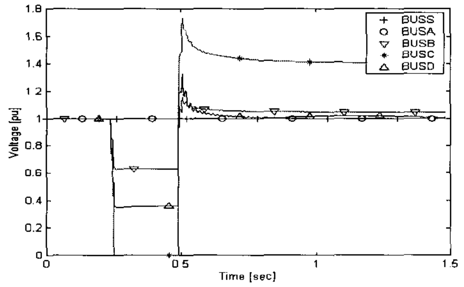

Fig. 9 Voltages at each bus under SLGF (BUSC) with DG

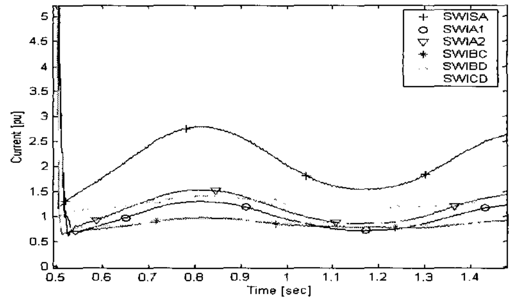

Fig. 10 Currents through each switch under SLGF (BUSC)

Post-fault voltage is restored to below 1.1[pu] against cases of no distributed generation. Also, currents show similar magnitude during fault, but currents are larger than those in the case of no distributed generation after fault.

Fig. 11 indicates waveforms of voltage under 3-phase fault condition. Voltages of all buses except faulted buses are restored to pre-fault voltage. However, a phenomenon of power swing at bus BUSD connected with distributed generation can be observed, and voltages at other buses are larger than those in the case of single line-to-ground fault.

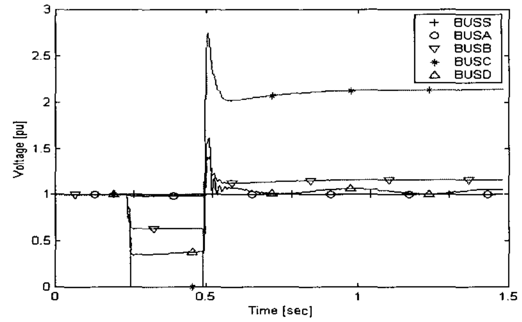

Fig. 11 Voltages at each bus under 3-phase fault with DG

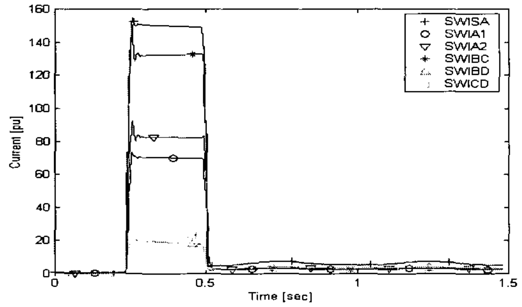

Fig. 12. Currents through each switch under 3-phase fault

Fig. 12 presents waveforms of currents through each switch. Because of the power generated by the synchronous generator, the trajectory of currents is different from the case in which there is no distributed generation.

Fig. 13 shows the effect of single line-to-ground fault at bus BUSC with distributed generation at bus BUSD in comparison with no distributed generation. As represented in Fig. 12, if distributed generation exists, voltages at each bus are restored to approximately 1.0[pu].

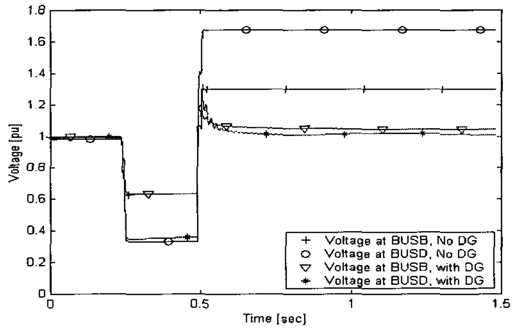

Fig. 13 Comparison of "No DG" case with "with DG" case

3.4 Minimum load, synchronous generator

In order to show the effects of distributed generation in case of minimum load, the case of minimum loads in Figure 3 is simulated. Figs. 14-15 present waveforms of voltage and current under single line-to-ground fault, respectively.

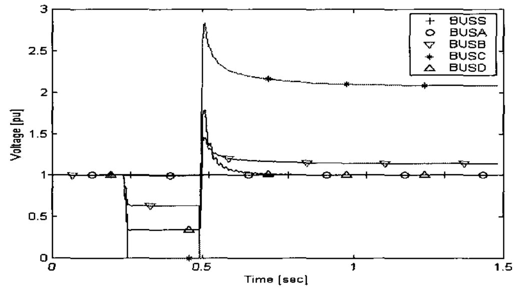

Fig. 14 Voltages at each bus under SLGF (BUSC)

As indicated in Fig. 15, in pre-fault state, the magnitude of currents is very small, around 0 [pu], but, during fault, its magnitude is equal to that shown in Figs. 5 and 7.

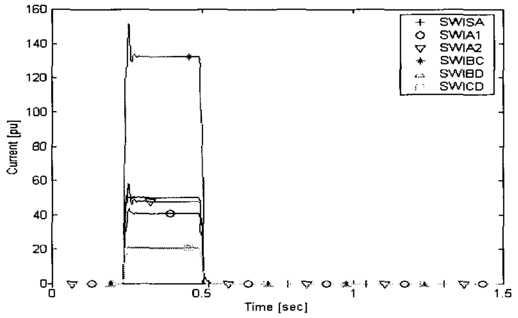

Fig. 15 Currents through each switch under SLGF (BUSC)

Fig. 16 indicates waveforms of voltage at bus BUSD under single line-to-ground fault in three types of system conditions. Voltage is restored to 1.0[pu] by synchronous generator after a fault, and voltage, in the case of minimum load quickly converges on pre-fault voltage against the case of maximum load.

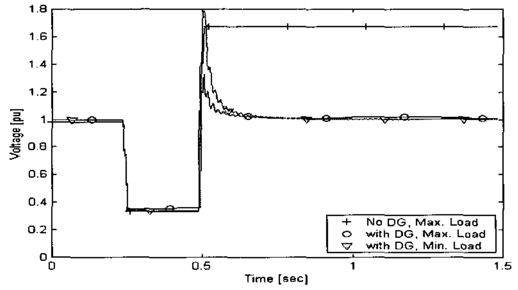

Fig. 16 Comparison of various cases of simulation

3.5 Summary

Faults have similar results at other locations such as BUSA, LineBD between BUSB and BUSD. Fig. 17 presents waveforms of voltages at bus BUSB and BUSD under three fault locations and two system conditions.

Table 4 shows RMS values of voltages and currents under other fault locations. Each value is measured in maximum load and DG case after the fault has cleared.

Table 4 Other fault locations

Voltage /Current	Normal Condition	F.L.*(BUSA)		F.L.*(lineBD)	
		SLGF	3-φ fault	SLGF	3-φ fault
BUSA [pu, V]	1.00	3.20	3.57	1.00	1.00
BUSB [pu, V]	1.00	1.54	1.65	1.08	1.10
BUSC [pu, V]	1.00	1.29	1.36	1.04	1.08
BUSD [pu, V]	1.00	1.01	1.1	1.01	1.07
lineBC [pu, I]	0.77	0.94~1.21	3.92~4.85	0.76~1.00	2.60~3.25
lineBD [pu, I]	1.04	1.43~1.74	5.89~7.01	1.16~1.43	3.90~4.68
lineCD [pu, I]	0.71	0.99~1.12	3.93~4.77	0.80~0.97	2.77~3.20

* F.L.: Fault Location

** Voltage: maximum value among phase A, B, C

*** Current: from minimum value to maximum value

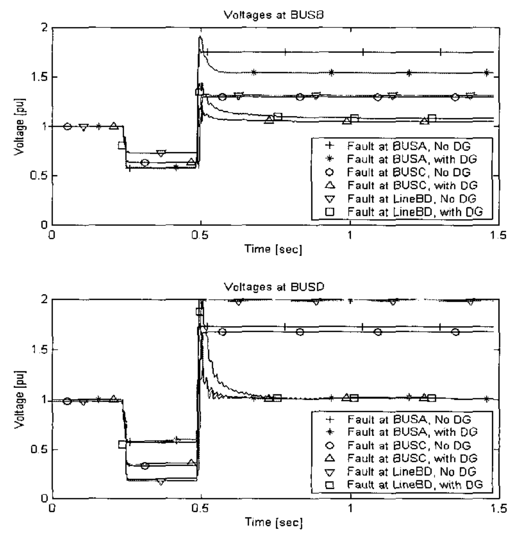

Fig. 17 Comparison of various conditions as fault location and existence of synchronous generator

Voltage at BUSD with DG is shown about 1.01~1.10 pu. However, currents have large magnitude and fluctuation. Particularly, currents have a large magnitude during fault condition. So, this situation is related to the capacity of the breaker, and breaker failure may occur.

Fig. 18 shows the waveform of voltage of phase A at bus BUSD under different fault durations. The fault type is single line-to-ground fault. As depicted in Fig. 18, the shorter the clearing time is, the better system stability will be. If fault continues for a long duration, then the synchronous generator loses synchronism and the system is unstable.

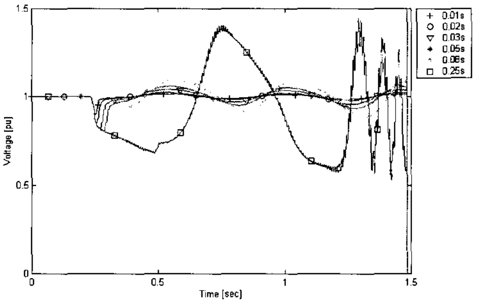

Fig. 18 Voltages at BUSD for different durations of fault

As indicated in Figure 18, if fault duration is below 0.02~0.03 [sec] (about 1~2 cycles), post-fault voltage more or less restores to pre-fault voltage. But, if the fault has a longer clearing time, fluctuation of voltage will be severe, and what is worse, the synchronous generator will lose synchronism.

4. Conclusion

Typically, when a fault occurs, the current is several times larger than a normal current. As such, power system engineers choose a breaker that is suitable to clear the fault. Nevertheless, if the power system is connected to DG, the fault current will be larger than if there is no DG and currents may fluctuate after the fault has cleared. Sometimes, the synchronous generator may lose synchronism.

A distribution network with distributed generation is simulated, and the system impact is analyzed by using EMTP. Simulation results show serious impact of the distributed generation under fault.

The power system engineer can choose new breakers, or establish new protection strategies. For example, when a fault occurs, the fault will be more quickly cleared and island distributed generator.

Acknowledgements

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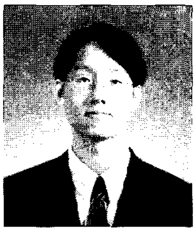

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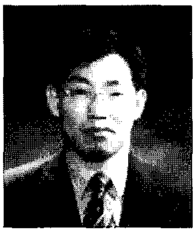

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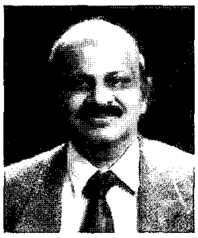

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