Effects of Reclosing according to the Size of Distributed Generation

Hun-Chul Seo , Hyun-Soo Park, Sang-Min Yeo, Chul-Hwan Kim*

Abstract— *An autoreclosing is used for the purpose of restoring the power system after a trip of the circuit breaker. The successful autoreclosing can enhance stability and reliability of the power system. The distributed generation (DG) is the small and medium size generator connected to distribution system. Because of the efficiency and productivity of the DG, the integration of DG to the distribution system will be increasing. On the other hand, it may cause the many problems of power system. For example, the maloperation of protective relay by distributed generation may be occurred. This paper analyzes the effects of reclosing according to size of DG, and suggests adaptive reclosing algorithm considering DG. The proposed algorithm consists of angle oscillation's judgment, Emergency Extended Equal-Area Criterion (EEEAC), calculation of optimal reclosing time, and reconnection algorithm. The algorithm is implemented by ATP/EMTP-MODELS. The simulation results show that the transient stability is maintained and the distributed generation is protected against disturbance***.

Keywords— **Distributed Generation, Autoreclosing, EMTP, Transient Stability**

1. INTRODUCTION

Distributed generation (DG) is a small-scale generator such as wind turbine, fuel cells, and photovoltaic systems. DG is expected for next-generation energy source because of resources exhaustion and environmental problem recently.

The implementation of these generations may influence the technical aspects of distribution systems. The operation of DG can cause unwanted operation of protection and the fault level may be changed [1]. As the penetration level of DG becomes higher, the impact of DG on transient stability cannot be neglected.

The autoreclosing can recover distribution lines, transmission lines and circuit breakers which are damaged by electrical faults. The successful autoreclosing can enhance a transient stability and the reliability of power systems. However, the unsuccessful autoreclosing may cause the system unstable and the damage of system and equipment. The presence of distributed generation can cause the unsuccessful autoreclosing because the DG may sustain feeding fault current during the autoreclose open time prohibiting the intended arc extinction [1]. Therefore, references [1-2] suggest that the DG must be disconnected clearly before the reclosing. But, the frequent disconnection of DG may cause the decrease of power quality, such as outage and voltage sag. In addition, the reconnection after disconnection of DG may cause the secondary transients to distribution systems.

This paper presents the adaptive reclosing algorithm including angle oscillation's judgment, EEEAC, calculation of optimal reclosing time, and reconnection algorithm. The algorithm decides the disconnecting of DG by means of angle oscillation's judgment and EEEAC and then the autoreclosing is performed. The simulation is performed by ATP/EMTP MODELS, and the simulated results show the effectiveness of the suggested schemes. By employing the suggested algorithm, we can maintain transient stability and improve the power quality while the DG is protected against disturbances.

2. FAULTS IN DISTRIBUTION SYSTEM

After clearing the fault, the secondary arc current begins to flow at fault point by mutual coupling between fault phase and sound phase. If the autoreclosing is performed without ascerating precisely the secondary arc currnet extinction, the arc may be re-established. So the fault can become permanent and the power system can be unstable. Therefore, the secondary arc current extinction must be confirmed for the successful autoreclosing and power system stability.

There are two types of distribution systems. First, the DG can be connected to the loop type distribution system. In this case, because the fault point is isolated from the power system by operating circuit breaker at both terminals, the current supplied by DG does not flow at fault point. And the secondary arc current extinction depends on length of transmission line and system voltage. Second, the DG can be also connected to the radial type distribution system. After clearing the fault, the current supplied by DG continues to flow at fault point.

Figure 1 and 2 show the loop type and radial type distribution system, respectively [3]. The DG is modeled

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H. C. Seo is with Korea Electrical Engineering & Science Research Institute, Seoul, Korea (corresponding author to provide phone: 82-2-882-3397; Fax: 82-2-883-0827; e-mail: hunchul12@snu.ac.kr)

H. S. Park is with the Sungkyunkwan University, Suwon, Korea, e-mail: sbsfamily@nate.com

S. M. Yeo is with the Sungkyunkwan University, Suwon, Korea, e-mail: harc@chollian.net

* C. H. Kim (corresponding author) is with the Sungkyunkwan University, Suwon, Korea , e-mail: hmwkim@hanmail.net

by synchronous generator in EMTP. And the arc model presented in [4] is used.

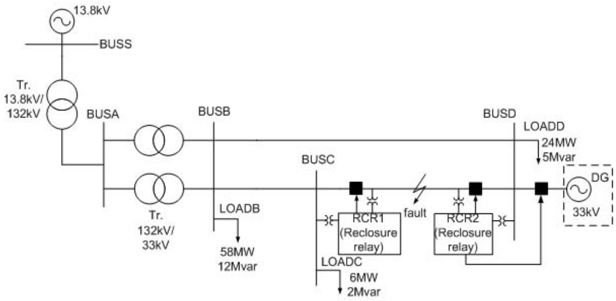

Fig. 1. Single-line diagram for loop type distribution system

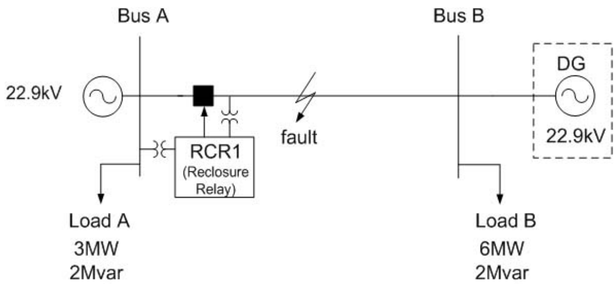

Fig. 2. Single-line diagram for radial type distribution system

Tables 1 and 2 show the system parameters for each type of distribution system, respectively.

Table 1. The system parameter for loop type system (Fig. 1)

From Bus	To Bus	Type	Resistance	Reactance
BUS S	BUS A	transformer	0	0.0667
BUS A	BUS B	transformer	0.0099	0.2088
BUS A	BUS B	transformer	0.0092	0.2170
BUS B	BUS C	line	0.0446	0.1917
BUS B	BUS D	line	0.2146	0.3429
BUS C	BUS D	line	0.2390	0.4163

Table 2. The system parameter for radial type system (Fig. 2)

From Bus	To Bus	Type	Resistance	Reactance
BUS A	BUS B	line	0.0446	0.1917

Figure 3 shows the secondary arc current extinction time according to size of DG in loop type distribution system. Figure 4 shows the secondary arc current extinction time according to size of DG in radial type distribution system.

In figure 3, we can find that the secondary arc current extinction time is not affected by the size of DG. As shown in figure 4, the secondary arc current extinction time may be affected by the DG size. However, the secondary arc current extinction time in figure 4 ranges from 0.0014s to 0.0016s, and these limits are very short. Therefore, we can conclude that the secondary arc current extinction time is not affected by the size of DG on radial type distribution network.

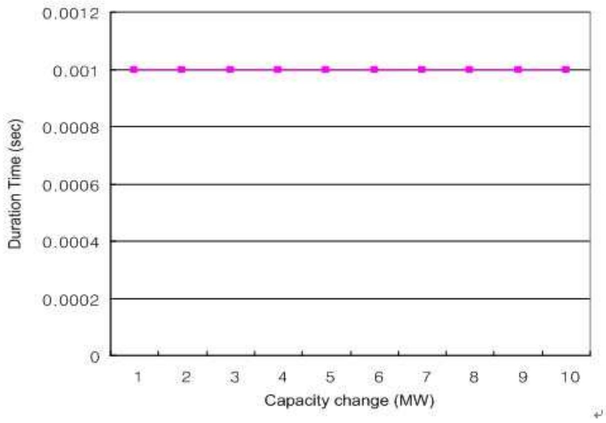

Fig. 3. Relation with duration time and capacity on loop type distribution network

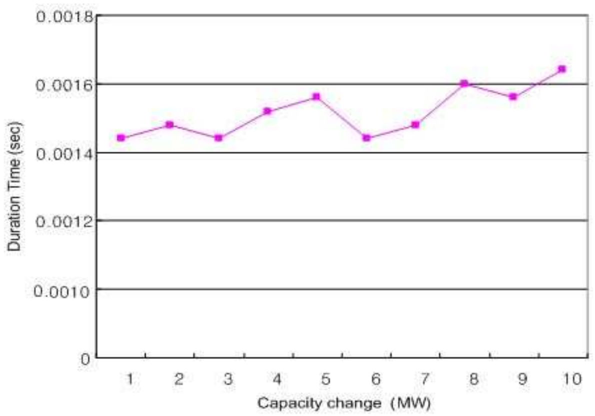

Fig. 4. Relation with duration time and capacity on radial type distribution network

Small-scale DG is linked to short distribution line length nowadays. In this case, the secondary arc current does not flow at fault point by neglecting the mutual coupling between the fault phase and sound phase. And the distribution system is more and more complex. Therefore, this paper supposes that 10MW DG is connected to the loop type distribution network.

3. AN ADAPTIVE RECLOSING TECHNIQUE WITH REFERENCE TO DISTRIBUTED GENERATION

Figure 5 shows the adaptive reclosing algorithms with reference to distributed generation. The impact of DG on power system transient stability depends on the technology of the DG. DG based on asynchronous generator does not have much impact on transient stability, but DG based on synchronous generator has much impact on transient stability [5]. Therefore, in order to distinguish DG based on synchronous generator from DG based on asynchronous generator, the adaptive reclosing algorithm firstly judges whether the phase angle between two buses is oscillated or not after fault clearing (block 1). If angle oscillation is not occurred, the autoreclosing will be performed without disconnecting DG. If angle oscillation is occurred, the EEEAC (block 2) will be used to estimate the transient stability in real-time. In stable case, the reclosing is performed at optimal reclosing time by block 3 without disconnecting DG, whereas, in unstable case, the DG is disconnected to prevent the loss of synchronism and then the autoreclosing is performed and DG is reconnected at instant (Tr) calculated by reconnection algorithm(block 4) after successful autoreclosing. Blocks 2, 3 are presented in [6] and blocks 1, 4 are following.

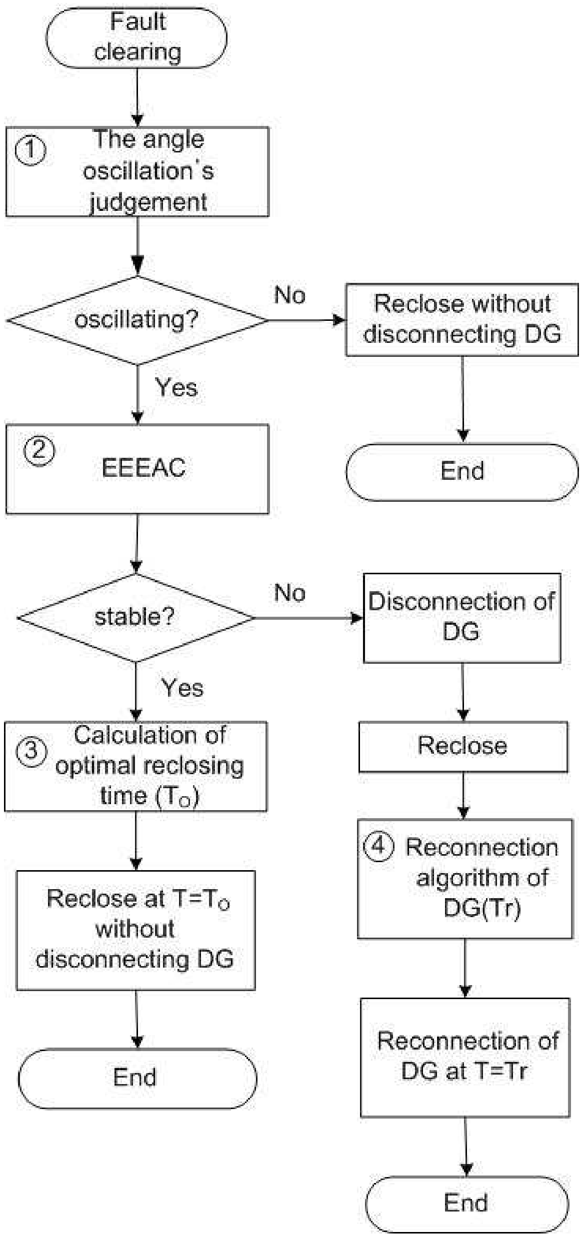

Fig. 5. The block diagram of adaptive reclosing algorithm

3.1 Angle oscillation's judgment

Figure 6 shows the phase angle oscillation's judgment method.

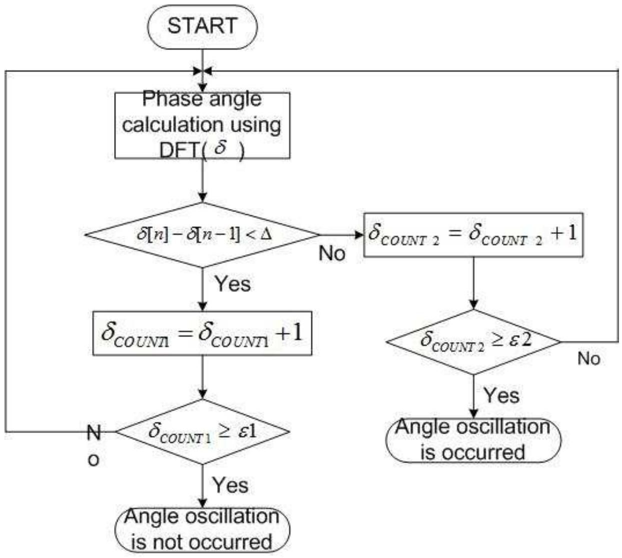

Fig. 6. The block diagram of angle oscillation's judgment method

The phase angle between two buses is calculated by using DFT. When difference-value between present phase angle and previous phase angle at each time step is less than Δ, where Δ is differential threshold that is used for judging the angle oscillation, δ_{COUNT1} is incremented.

Otherwise, δ_{COUNT2} is incremented. δ_{COUNT1} and δ_{COUNT2} are counter. If δ_{COUNT1} is greater than ε_1, angle oscillation is not occurred and if δ_{COUNT2} is greater than ε_2, angle oscillation is occurred. ε_1 and ε_2 are sample number.

The whole process is based on a moving window approach whereby a 1-cycle window is moved continuously by 1 sample and the sampling rate is 12 samples/cycle at 60Hz. The optimal setting for Δ, ε_1 and ε_2 are 0.01, 24 and 24, respectively.

3.2 The reconnection algorithm of DG

To prevent the instability of power system, DG is disconnected and then the autoreclosing is performed. In order to maintain reliability and safety of the distribution system, DG should be reconnected to the power system. The following is the KEPCO's rule for reconnection of DG.

- After recovery of power system disturbance, DG must be reconnected to the distribution system only if the power system voltage and frequency is maintained for five minutes in steady state.

Based on above rule, figure 7 shows the reconnection algorithm of DG.

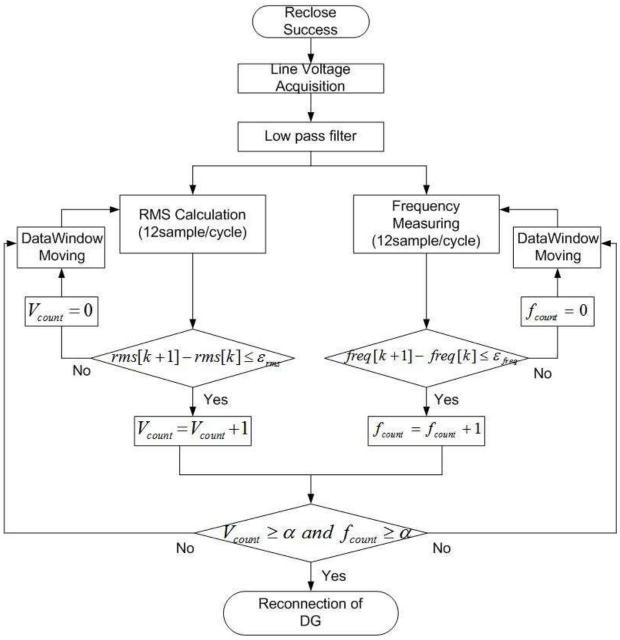

Fig. 7. The block diagram of reconnection algorithm

The RMS value of line voltage is calculated and the power system frequency is measured by using DFT. The algorithm is based on the difference-value between present value and previous value at each time step for voltage and frequency, respectively. If these difference-values are less than threshold, the power system is considered as steady state and then V_{count} and f_{count} are incremented. In figure 7, α is sample number, which means the steady state duration time. If the setting for α is 216,000, the steady state duration time is five minutes.

4. SIMULATION AND RESULTS

4.1 System model studied

The Electro-Magnetic Transient Program (EMTP) has been used for power system analysis under transient and dynamic conditions. It consists of a library of models of network components such as electrical machines, transformers, lines, etc. that can be interconnected together to simulate any required electrical network [7]. The reclosure relays are implemented through ATP/EMTP MODELS, which makes it possible to simulate the interaction between the power system and the relay [8].

Model system of distribution system for simulation is shown in Figure 1, which is interfaced with the reclosure relays (RCR1 and RCR 2 in figure1). The RCR2 controls the connection of DG as well as reclosing of circuit breaker. Model system has 5 buses, 3 transformers, and 3 loads. The uncoupled, lumped series branches by Type 0 in ATP/EMTP are used for distribution line.

The synchronous generator is modeled by Type 59 model. Double line to ground fault with duration of 0.167s is assumed on distribution line between BUS C and BUS D.

4.2 Simulation Results

4.2.1 When the proposed algorithm is not employed

Figure 8 shows the variation of the phase angle between two buses when DG based on synchronous generator is employed. In this case, although the synchronisms are lost as shown in figure 8, DG is not disconnected. As shown in figure 9, model system is unstable. The instability can be avoided by employing the suggested autoreclosing algorithm.

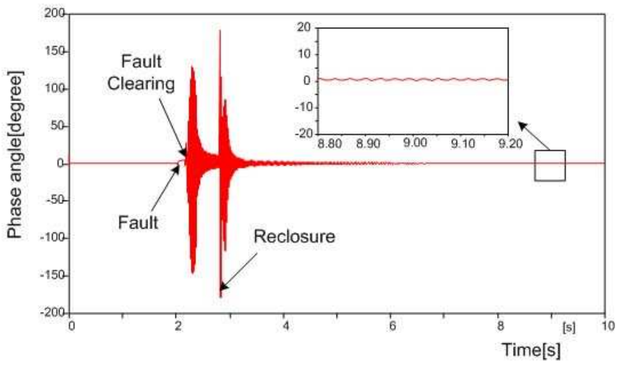

Fig. 8. Phase angle between two buses when DG based on synchronous generator is employed (The suggested algorithm is not employed).

4.2.2 When the proposed algorithm is employed

4.2.2.1 When the transient stability estimation by EEEAC is stable

Figure 9 shows the variation of the phase angle between two buses when DG based on synchronous generator is employed. After fault clearing, the angle oscillation is occurred so that the transient stability is assessed in real-time by EEEAC. In this case, the swing is stable, and hence the optimal reclosing time is calculated. The tripped line is reclosed 0.9s after the tripping of the circuit breakers. As shown in figure 8, the power system stability is maintained.

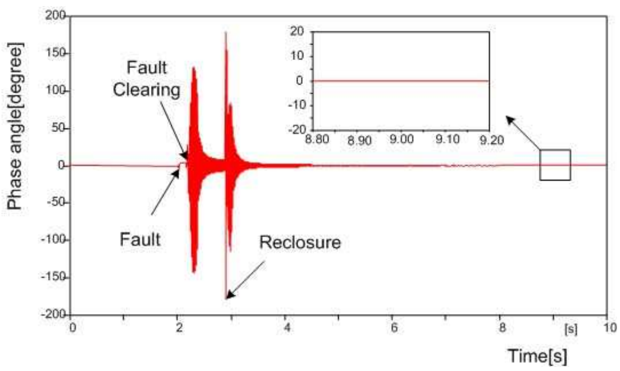

Fig. 9. Phase angle between two buses when DG based on synchronous generator is employed.

4.2.2.2 When the transient stability estimation by EEEAC is unstable

In unstable case, DG is disconnected by employing the suggested autoreclosing algorithm. The disconnection of DG unit causes a loss of generating sources, which leads to power quality drop and changes of protection settings. Therefore, DG has to be reconnected to the power system as soon as possible.

In this paper, the reconnection time based on KEPCO's rule and the faster reconnection time are simulated, and simulation results are analyzed. To compare the reconnection time based on KEPCO's rule with the faster reconnection time, two indicators, i.e. maximum deviation and oscillation duration, have been applied to the oscillations of the frequency and phase angle between two buses after reconnection of DG. The setting of faster reconnection time is assumed 5s, which is implemented by setting 3,600 at α in figure 7.

1) Frequency

Figures 10 and 11 depict, respectively, the frequency variation when the reconnection time (five minutes) based on KEPCO's rule and the faster reconnection time (five seconds) is applied. Table 3 shows the maximum deviation and oscillation duration after reconnection of DG. Two cases have an equal duration time, while the maximum deviation of reconnection time based on KEPCO's rule is greater than it of faster reconnection time, as shown in table 3.

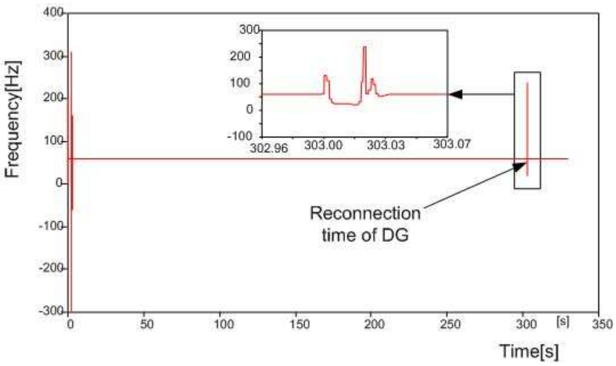

Fig. 10. Frequency variation when the reconnection time based on KEPCO's rule is applied.

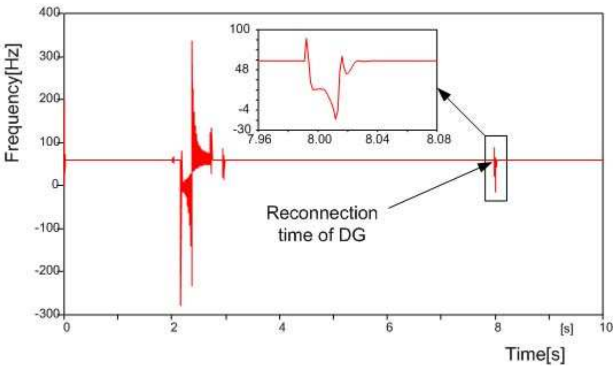

Fig. 11. Frequency variation when the faster reconnection time is applied.

Table 3. Maximum deviation and oscillation duration of frequency

Indicator / Reconnection time	Maximum deviation	Oscillation duration
Five minutes	218Hz	0.035s
Five seconds	104Hz	0.035s

2) Phase angle between two buses

Figures 12 and 13 depict, respectively, the phase angle between two buses when the reconnection time (five minutes) based on KEPCO's rule and the faster reconnection time (five seconds) are applied. Table 4 shows the maximum deviation and oscillation duration after reconnection of DG. Two cases have an equal duration time, while the maximum deviation of reconnection time based on KEPCO's rule is greater than it of faster reconnection time, as shown in Table 4.

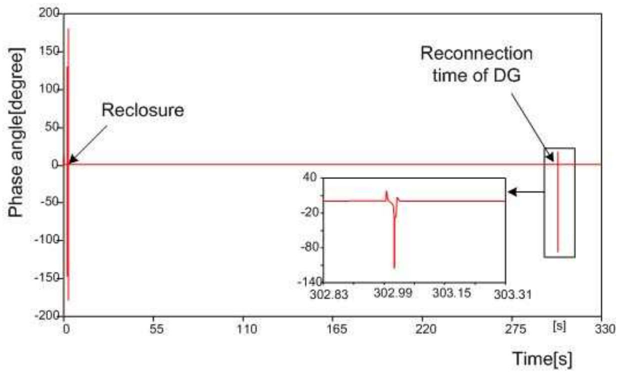

Fig. 12. Phase angle variation between two buses when the reconnection time based on KEPCO's rule is applied.

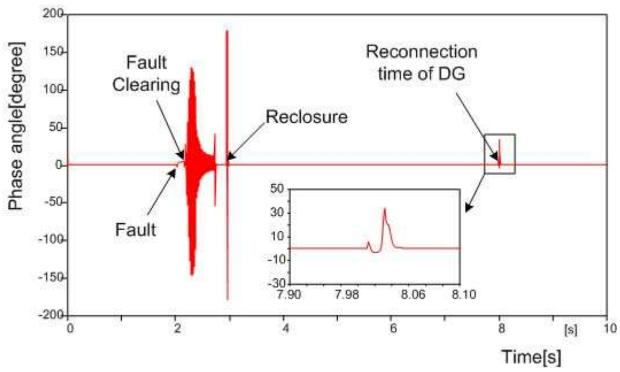

Fig. 13. Phase angle variation between two buses when the faster reconnection time is applied.

Table 4. Maximum deviation and oscillation duration of phase angle variation between two buses

Indicator / Reconnection time	Maximum deviation	Oscillation duration
Five minutes	132°	0.05s
Five seconds	22.5°	0.05s

4.2.2.3 Discussion

As shown in tables 3 and 4, oscillation duration is equal, while maximum deviation for case of five seconds is less than maximum deviation for case of five minutes. These results support that the reconnection time of five seconds is more efficient. Therefore, in the reliability and safety point of view, DG has to be reconnected at the faster time than reconnection time based on KEPCO's rule if possible.

5. CONCLUSIONS

This paper has presented an adaptive autoreclosing technique with reference to distributed generation for improving and maintaining the system stability. The proposed autoreclosing technique is composed of four blocks, i.e. the angle oscillation's judgment, calculation of optimal reclosing time, EEEAC and reclosing algorithm. The proposed autoreclosing algorithm is verified and tested for distribution system with DG, namely synchronous generator.

The simulation results show that the transient stability for all cases is maintained by using proposed autoreclosing technique. Specially, when DG unit is disconnected, it is verified that reconnection of DG needs to be performed faster than the reconnection time based on KEPCO's rule. The adaptive autoreclosing technique presented herein can be useful in protection and efficient operation of DG.

Although the development on DG, e.g. wind turbine, fuel cells, and photovoltaic systems grows significantly, the penetration of DG is still low in KEPCO's system. If increasing amounts of DG is connected to electrical power systems by growing concern over CO_2 emissions and technological developments, the interest on reclosing for power system protection will be also increased. Moreover, in the future, the KEPCO's distribution system will become the complex system that has many short distribution lines, various loads, and generation sources. In this trends, the suggested reclosing algorithm better than current KEPCO's rule will have the potential for application in KEPCO's system.

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