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An Adaptive Reclosing Algorithm Considering Distributed Generation

Hun-Chul Seo and Chul-Hwan Kim

Abstract: Autoreclosing techniques have been used in power systems to maintain system stability and continuity of supply. Environmental and economical issues have driven significant increases in the development of distributed generation (DG). DG connected to distribution systems, however, may impose negative influences with respect to power quality, protection, and stability, because DG can cause some challenges to protection, especially to reclosing. For this reason, in order to improve the reliability and safety of the distribution system, the rules and guidelines suggest that the DG system needs to be rapidly disconnected from the system before reclosing. We present, in this paper, an adaptive reclosing algorithm considering the DG. The algorithm consists of an angle oscillation's judgment, the emergency extended equal-area criterion (EEEAC), the calculation of an optimal reclosing time, and a reconnection algorithm. Our simulation results for three different DG technologies with Electromagnetic Transient Program (EMTP) indicate that we can maintain transient stability while the DG is protected against disturbances.

Keywords: Adaptive reclosing, distributed generation, EMTP, transient stability.

1. INTRODUCTION

We expect that several DG technologies, e.g. the wind turbine, fuel cells, and photovoltaic systems, will be connected to the distribution system. The implementation of these power generations can cause the deterioration of power quality and reliability and threaten protection coordination, transient stability, and etc. The fast detection and clearing of faults are the fundamental way to protect against system damages which are caused by transient instability. Reclosing is the next best thing. The presence of DG can cause other problems which have not occurred in conventional distribution systems. DG may sustain feeding fault current interrupting the intended arc extinction during the autoreclose open time. Therefore, the successful reclosing cannot achieve [1]. If the unsuccessful reclosing is occurred, then the distribution system cannot remain stable. Therefore, several researchers suggest that the DG must be clearly disconnected before the reclosing [1,2]. But, the frequent disconnection of the DG may cause deterioration of power quality. Also, the reconnection after a disconnection of DG systems may again cause transients in the distribution system.

We present an adaptive reclosing algorithm including an angle oscillation's judgment, the EEEAC, a calculation of the optimal reclosing time, and the reconnection algorithm. The algorithm decides the disconnecting of the DG by means of an angle oscillation's judgment and the EEEAC. Then, the autoreclosing is performed. We have performed simulation for the three different DG technologies using EMTP MODELS [3]. The simulation results showed the effectiveness of the suggested schemes.

2. THE EFFECT OF THE DISTRIBUTED GENERATION ON ARC FAULT

Several factors are important to consider before attempting to autoreclose. An autoreclose attempt without sufficient time delay for arc extinction results in an unsuccessful event [2]. Therefore, we firstly discuss the effects of the DG for the arc extinction in various distribution systems

2.1. Line model in EMTP

In this paper, the arc model in reference [3,4] is adopted and is modeled by using EMTP MODELS. The primary arc can be modelled by using a time-varying resistance by Transient Analysis of Control System (TACS) Type-91. However, the secondary arc occurs by mutual coupling of the faulted phase with the health phase so that the line model considering mutual coupling must be used to simulate the secondary arc by the EMTP.

We modelled the long transmission line by using the distributed line model using LINE CONSTANTS in the EMTP; while we modelled the distribution line

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Hun-Chul Seo and Chul-Hwan Kim are with the School of Information and Communication Engineering, Sungkyunkwan University, Suwon-city, Gyeonggi-do 440-746, Korea (e-mails: {hunchul 0119, hmwkim}@hanmail.net).

by using the PI model and lumped series model according to the line length. The distributed line model and PI model, considering mutual coupling, can simulate the secondary arc. But, the lumped series model is not considered to be mutual coupling so it cannot simulate the secondary arc [5].

2.2. The effect of the DG according to the distribution system configuration

2.2.1 A loop type distribution system model

Fig. 1 shows the loop type distribution system model with the DG [6]. In this type, the existence of the DG does not have an effect regardless of the line length of the distribution system because both circuit breakers of the linked bus are tripped.

2.2.2 A radial type distribution system model

Fig. 2 shows the radial type distribution system model with the DG. Most of the distribution systems including the Korea Electric Power Corporation (KEPCO)'s system are the radial type system model. When a fault occurs, the circuit breaker of the source side (CB in Fig. 2) is tripped. If the DG is not connected to the system or disconnected promptly after the fault occurrence, the current does not flow into the fault point. However, if the DG is connected to the system, the current continues to flow into the fault point. In this case, we must consider the two line models, namely the PI model and the lumped series model.

First, when the PI model for the line of the distribution system with the DG is used, mutual coupling is considered. Therefore, in this case, the secondary arc is established after clearing the fault. The secondary arc extinguishes when the restrike voltage is bigger than the fault voltage by mutual coupling. For this reason, successful autoreclosing is only performed when the secondary arc extinguishes and the restrike voltage is bigger than the system voltage. Herein, if the DG is not connected to the system, the line voltage after tripping the circuit breaker is dead and the fault voltage by mutual coupling is little so the secondary arc extinguishes very fast. However, if the DG is connected to the system, the voltage injected by the DG exists in the fault line so it takes the time until the restrike voltage is bigger than the fault voltage and hence the secondary arc extinction is delayed.

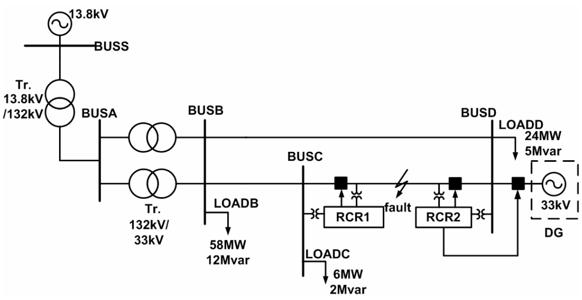


Fig. 1. A loop type distribution system model.

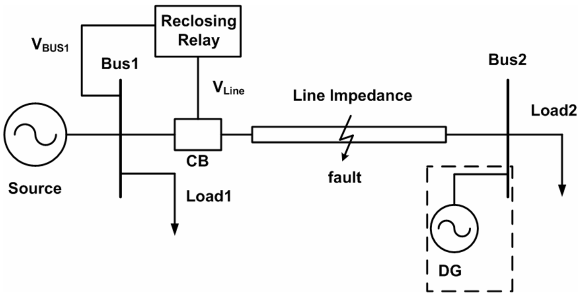


Fig. 2. A radial type distribution system model.

Second, when the distribution line is short, the line composed of the resistance and inductance is considered. In this case, the mutual coupling is neglected so the secondary arc does not occur although the fault current is injected to the line by the DG.

2.3. EMTP simulation

2.3.1 The loop type distribution system model

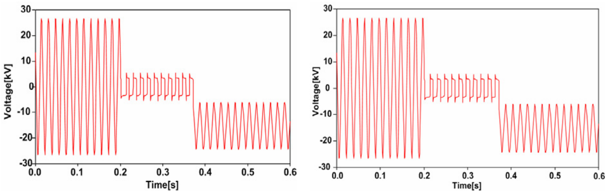
The arc fault is simulated in the loop type system model of Fig. 1 by using EMTP. The two cases, the PI model and the lumped series model, are simulated for analyzing the effect of the DG according to the line length.

1) Case 1 - The PI model

Fig. 3(a) depicts the fault point voltage when the DG is not connected to the system. The fault occurs at 0.2 seconds and is cleared after 10 cycles; thereafter, the recovery voltage waveform appears. Therefore, we recognize that the secondary arc extinguishes promptly after clearing the fault. Fig. 3(b) shows the fault point voltage when the DG is connected to the system. In this case, we can also recognize that the secondary arc extinguishes promptly after clearing the fault through the recovery voltage waveform. As shown in Fig. 3, the results of the two cases are equal. Therefore, when the PI model is employed, the effect of the DG can be ignored. Also, the rms value of the line voltage can be used to detect secondary arc extinction.

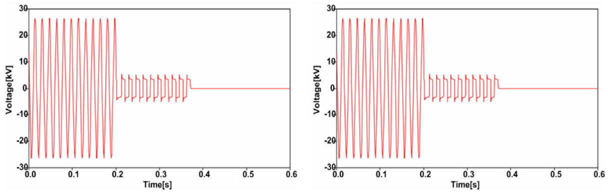
2) Case 2 - The lumped series model

Fig. 4(a) shows the fault point voltage when the DG



(a) without DG. (b) with DG.

Fig. 3. The effect of the DG when the PI model is employed.



(a) without DG. (b) with DG.

Fig. 4. The effect of the DG when the lumped series model is employed.

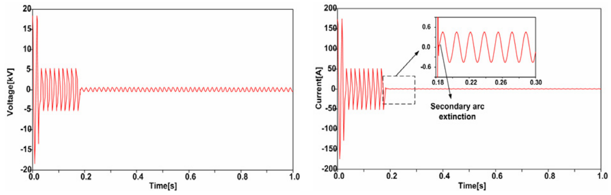
is not connected to the system. The fault occurs at 0.2 seconds and is cleared after 10 cycles. The nonlinear arc voltage waveform appears during the fault and the line voltage is zero after clearing the fault as shown in Fig. 4(a). We can find that the secondary arc is not established since the lumped series model in EMTP does not take into consideration the mutual coupling between the phases. Fig. 4(b) shows the fault point voltage when the DG is connected to the system. This result is equal to Fig. 4(a). As shown in Fig. 4, when the DG is connected to the short line distribution system, the effect of the DG can be ignored. Although, the secondary arc extinction cannot be detected from the rms value of the line voltage, it extinguishes very fast in a low voltage and short line distribution system.

2.3.2 The radial type distribution system model

In the radial type system model of Fig. 2, the arc fault is simulated by using EMTP. The two cases, the PI model and the lumped series model, are also simulated for analyzing the effect of the DG according to the line length.

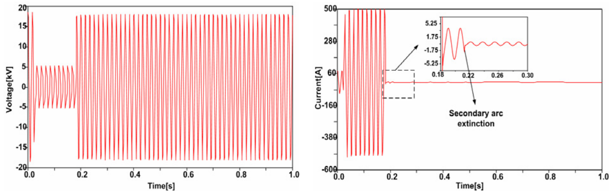
1) Case 1 - The PI model

Fig. 5 shows the fault point voltage and the fault line current when the DG is not connected to the system. The fault is occurred at 0.02 seconds and cleared after 10 cycles. After tripping the circuit breaker, the low voltage and current were found. These results show that the secondary arc rapidly extinguishes after clearing the fault. Fig. 6(a) shows the fault point voltage when the DG is connected to the system. After clearing the fault, a voltage similar to the steady state voltage appeared. This phenomenon resulted from the injected current by the DG. Hence, the secondary arc extinction was not confirmed from the fault voltage waveform. Fig. 6(b) shows the fault line current which flowed from fault point to Bus 2. After clearing the fault at 0.18 seconds, we recognized that the secondary arc that was extinguished at 0.216 seconds occurred. Also, in this Fig. 6, we can find that the low current was flowing after the secondary arc extinction. These results showed that the secondary arc extinction was delayed by the injected fault current by the DG when the DG was connected to the system and the PI model was employed. In these cases, the fault line current can be used for detecting the secondary arc extinction.



(a) Fault point voltage. (b) Fault line current.

Fig. 5. Fault voltage and current when the DG is not connected to the system (the PI model is employed).

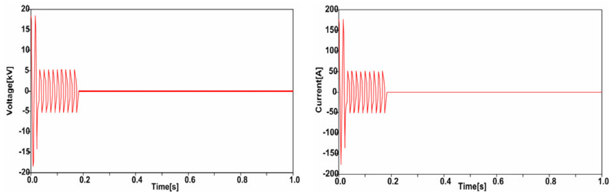


(a) Fault point voltage. (b) Fault line current.

Fig. 6. The fault voltage and current when the DG is connected to the system (The PI model is employed).

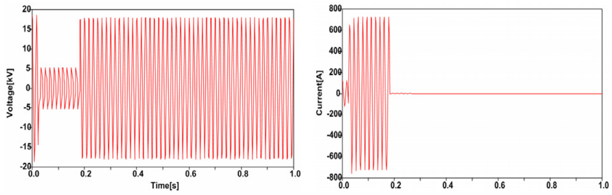
2) Case 2 - The lumped series model

Fig. 7 shows the fault point voltage and the fault line current when the DG is not connected to the system. Fig. 7 shows that the secondary arc was not established because the lumped series model in EMTP did not consider mutual coupling between the phases after clearing the fault. Fig. 8 shows the fault point voltage and the fault line current when the DG is connected to the system. After clearing the fault, the voltage was in the fault line and the secondary arc was not established, as shown in Figs. 8(a) and (b). Fig. 8



(a) Fault point voltage. (b) Fault line current.

Fig. 7. The fault voltage and current when the DG is not connected to the system (the lumped series model is employed).



(a) Fault point voltage. (b) Fault line current.

Fig. 8. The fault voltage and current when the DG is connected to the system (the lumped series model is employed).

shows that the effect of the DG can be ignored when the DG is connected to the radial type and short line distribution system. These results are similar to the above 2.3.1 - 2).

3. AN ADAPTIVE RECLOSING TECHNIQUE CONSIDERING THE DISTRIBUTED GENERATION

We analyzed the effect of the DG according to the system configuration for the arc fault. When the DG is connected to the short line distribution system, the effect of the DG on the secondary arc can be neglected regardless of the system configuration. However, When the DG is connected to the medium line distribution system, the secondary arc can be sustained with the injected current from the DG.

Currently, most DG systems are connected to the short line distribution system near the load as small capacity. Therefore, our work considered the DG which was connected to the short line distribution system so that our work assumed that the secondary arc extinguished very fast or was not established.

As the penetration level of the DG, which means the total DG power generation over the total load demand, was increasing, the problems in relation to transient stability were also increasing. References [7-12] presented that the swing of the generator on the distribution system view can cause the swing of power and frequency and the transient stability can be enhanced if the DG is properly connected to the system and the penetration level of the DG is increased. Therefore, as the penetration level of the DG increases, the power system transient stability must be considered. For estimating the transient stability, we first studied the possibility of an equal-area criterion application. The equal-area criterion estimates the transient stability by using the plots of electrical power and mechanical power of the generator versus the power angle. In the case of a radial type, the selection of two buses for the power angle calculation has the difficulty. On the other hand, the loop type is easier than the radial type for the equal-area criterion application. A distribution system with DG is a multi-machine system that makes an application of the expanded equal-are criterion (EEAC). Also, an EEEAC based on the EEAC can be applied to predict and estimate the degree of transient stability in real-time. In addition, as the DG connected to the distribution system is increasing, the loop type distribution system is also increasing. Therefore, we suggest an adaptive reclosing technique which can be applied in a loop type distribution system.

Fig. 9 shows the adaptive reclosing algorithms considering the distributed generation. The impact of a DG system on the power system's transient stability depends on the technology of the DG. The DG based on an asynchronous generator does not have much impact on transient stability, but the DG based on a synchronous generator has a much bigger impact on transient stability [10]. Therefore, in order to distinguish a DG based on a synchronous generator from DG based on an asynchronous generator, the adaptive reclosing algorithm first judges whether the phase angle between two buses is oscillating or not after clearing the fault(block①). If the angle oscillation has not occurred, then autoreclosing is performed without disconnecting the DG. If an angle oscillation has occurred, the EEEAC(block ②) is used to estimate transient stability in real-time. In the stable case, the reclosing is performed at an optimal reclosing time by block ③ without disconnecting the DG; whereas, in an unstable case, the DG is disconnected to prevent the loss of synchronism. After this disconnection, the autoreclosing is performed and the DG is reconnected at an instant (Tr) calculated by the reconnection algorithm (block④) after successful

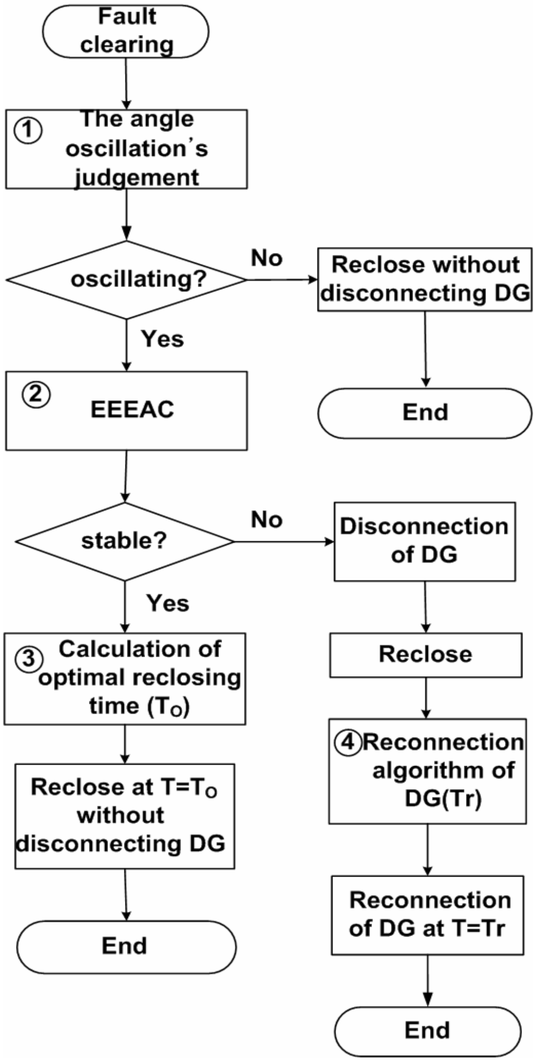


Fig. 9. A block diagram of the adaptive reclosing algorithm.

autoreclosing. Blocks ② and ③ are presented in [13-15] and blocks ① and ④ are the following.

3.1. Angle oscillation's judgment

Fig. 10 shows the phase angle oscillation's judgment method. The phase angle between the two buses is calculated by using Discrete Fourier Transform (DFT). When the difference-value between the present phase angle and the previous phase angle at each time step is less than Δ, where Δ is the differential threshold that is used for judging the angle oscillation, then δ_{COUNT1} is incremented. Otherwise, δ_{COUNT2} is incremented. δ_{COUNT1} and δ_{COUNT2} are counters. If δ_{COUNT1} is greater than ε_1, the angle oscillation has not occurred and if δ_{COUNT2} is greater than ε_2, the angle oscillation has occurred. The terms, ε_1 and ε_2, are the sample numbers.

The whole process is based on a moving window approach whereby a 1-cycle window is moved continuously by one sample and the sampling rate is 12 samples/cycle at 60Hz. The optimal settings for Δ, ε_1, and ε_2 in this paper are 0.01, 24, and 24, respectively. The setting values of these thresholds are dependent on the application environments [3].

3.2. The reconnection algorithm of the DG

To prevent the instability of the power system, the DG is disconnected and then the autoreclosing is performed. If the DG is not reconnected to the system, this means the loss of the generator source so that various problems, such as power quality, protection, etc, can occur. Therefore, when the DG is immediately disconnected from the system after the fault inception, the DG must be reconnected to the system after successful reclosing. The following is KEPCO's rule for reconnection of the DG.

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

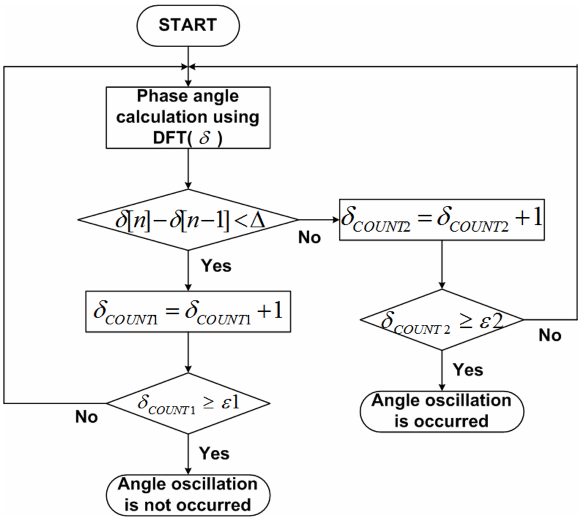


Fig. 10. A block diagram of the angle oscillation's judgment algorithm.

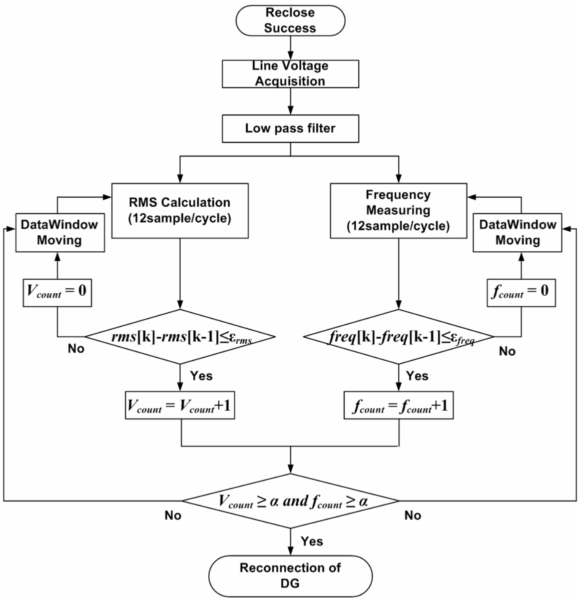


Fig. 11. A block diagram of the reconnection algorithm.

Based on the above rule, Fig. 11 shows the reconnection algorithm for the DG. The RMS value of the line voltage is calculated and the power system frequency is measured by using a DFT. The algorithm is based on the difference-value between the present value and the previous value at each time step for the voltage and frequency, respectively. If these difference-values are less than the threshold, the power system is considered as being in steady state and then V_{count} and f_{count} are incremented. In Fig. 11, α is a 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

4.1. The system model studied

The distribution system model for the simulation is shown in Fig. 1. This model was interfaced with the reclosure relays implemented through the EMTP MODELS. The RCR2 of the reclosure relays controlled the connection of the DG as well as the reclosing of the circuit breaker. The model system had 5 buses, 3 transformers, and 3 loads. The uncoupled, lumped series branches of Type 0 of the EMTP line models were used for distribution line modelling. A two phase to ground fault with duration of 0.167 seconds occurred on the distribution line between Bus

C and Bus D.

We studied three different distributed generation technologies:

- Synchronous generator
- Induction generator
- Power electronics

The synchronous generator was simulated by a Type 59 model and the induction generator was simulated by a Universal Machine (UM) model. In the case of power electronics, a three phase PWM inverter was used.

The operation time of each algorithm described in this paper was ① The angle oscillation's judgement: 2 cycles after the fault inception, ② EEEAC: 33cycles after the fault inception, and ③ and ④ could not be specified in the operation time because ③ the optimal reclosing time was calculated by using the power angle after clearing the fault and ④ the reconnection time was calculated by using the power system frequency and voltage after successful reclosing.

4.2. Synchronous generator

4.2.1 The stable case

Fig. 12 shows the variation of the phase angle between the two buses when the DG based on a synchronous generator was employed. The initial phase angle between two buses is 0.08°. After clearing the fault, the angle oscillation occurred so that the degree of transient stability was predicted by using EEEAC in real-time. In this case, the swing was stable, and hence the optimal reclosing time was calculated. The tripped line was reclosed at 0.9 seconds after the tripping of the circuit breakers. As shown in Fig. 12, power system stability was maintained.

4.2.2 Unstable case

In this case, the initial phase angle between two buses is 0.69°, so that the swing was unstable.

In the unstable case, the DG was disconnected by employing the suggested reclosing technique. The disconnection of the DG caused a loss of generating sources. These losses lead to the deterioration of power quality and the change of protection settings. Therefore, the DG had to be reconnected to the power system as soon as possible.

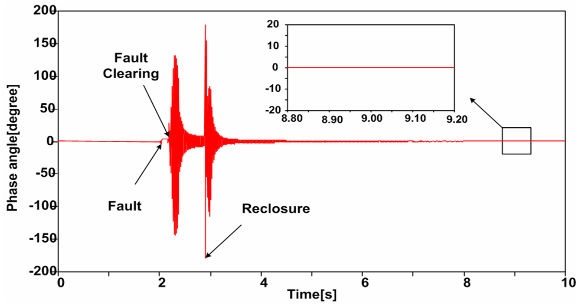


Fig. 12. The phase angle between two buses when the DG based on the synchronous generator was employed.

In our work, we simulated the reconnection time based on KEPCO's rule and the faster reconnection time and analyzed the simulation results. To compare the reconnection time based on KEPCO's rule with the faster reconnection time, two indicators, i.e. the maximum deviation and oscillation duration [10], were applied to the oscillations of the frequency and phase angle between the two buses after the reconnection of the DG. The setting of the faster reconnection time was assumed to be 5 seconds which was implemented by setting 3,600 at α in Fig. 11.

1) Frequency

Figs. 13 and 14 depict the frequency variation when the reconnection time (five minutes) based on KEPCO's rule and when the faster reconnection time (five seconds) were applied, respectively.

Table 1 shows the maximum deviation and oscillation duration of the frequency after reconnection of the DG. There were two cases that had an equal duration time, while the maximum deviation of reconnec-

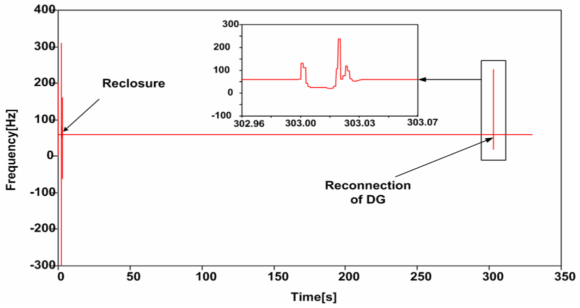


Fig. 13. The frequency variation when the reconnection time based on KEPCO's rule was applied.

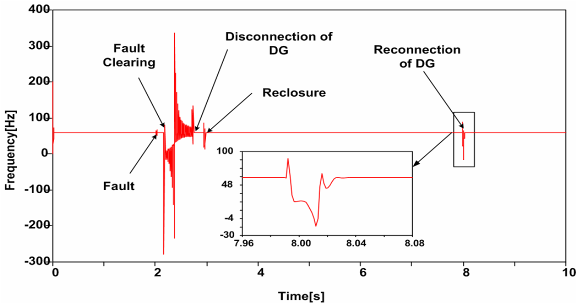


Fig. 14. The frequency variation when the faster reconnection time was applied.

Table 1. The maximum deviation and oscillation duration of the frequency.

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

tion time based on KEPCO's rule was greater than that of a faster reconnection time, as shown Table 1.

2) Phase angle between two buses

Figs. 15 and 16 depict the phase angle between the two buses when the reconnection time (five minutes) based on KEPCO's rule and the faster reconnection time (five seconds) were applied, respectively.

Table 2 shows the maximum deviation and oscillation duration of the phase angle between two buses after reconnection of the DG. Two cases had an equal duration time while the maximum deviation of the reconnection time based on KEPCO's rule was greater than that of a faster reconnection time, as shown Table 2.

3) Discussion

In the two cases, the oscillation durations were equal while the maximum deviation for the case of five seconds were less than the maximum deviation for the case of five minutes, as shown in Tables 1 and 2. These results supported the assertion that the reconnection time of five seconds was more efficient. Therefore, in view of the power quality and efficiency, it was possible that the DG was reconnected at the faster time than the reconnection time based on KEPCO's rule.

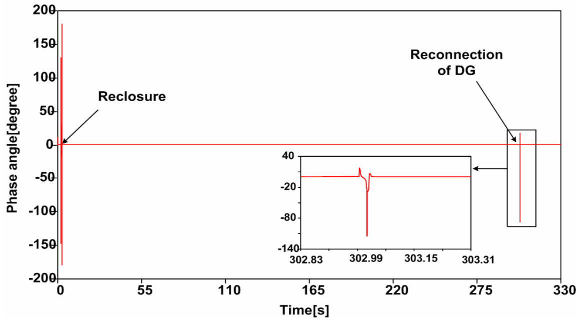


Fig. 15. The phase angle variation between two buses when the reconnection time based on KEPCO's rule was applied.

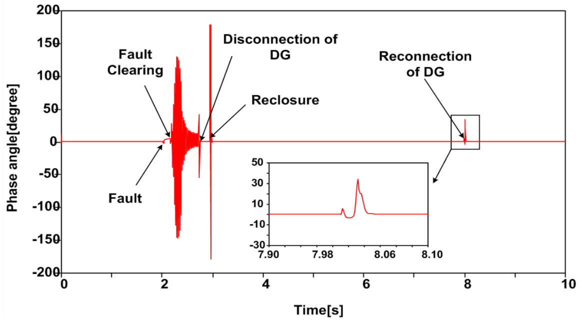


Fig. 16. The phase angle variation between two buses when the faster reconnection time was applied.

Table 2. The maximum deviation and oscillation duration of the phase angle between two buses.

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

4.3. Induction generator

Fig. 17 shows the variation of the phase angle between the two buses when the DG based on an induction generator was employed. After clearing the fault, the angle oscillation did not occur and hence no DG was disconnected. The tripped line was reclosed at 0.8 seconds after the tripping of the circuit breakers. As shown in Fig. 17, power system stability was maintained.

4.4. Power electronics

Fig. 18 depicts the variation of the phase angle between the two buses when the DG based on power electronics was employed. After clearing the fault, the angle oscillation did not occur; therefore, no DG was disconnected. The tripped line was reclosed at 0.8 seconds after the tripping of the circuit breakers. The power system stability was maintained as shown in Fig. 18.

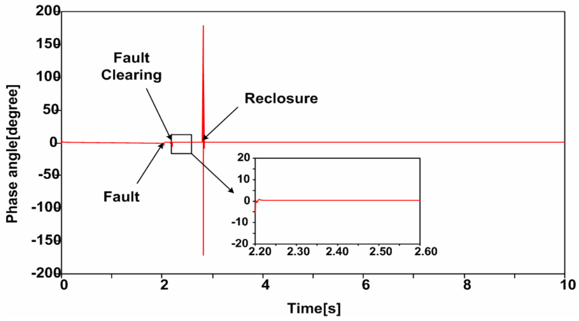


Fig. 17. The phase angle between the two buses when the DG based on an induction generator was employed.

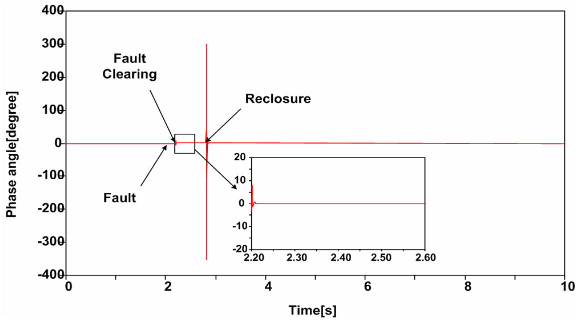


Fig. 18. The phase angle between the two buses when the DG based on power electronics was employed.

5. CONCLUSIONS

We presented an adaptive reclosing technique considering the distributed generation for improving and maintaining system stability. The proposed reclosing technique was composed of four blocks: the angle oscillation's judgment, the calculation of the optimal reclosing time, EEEAC, and the reconnection algorithm. We verified the proposed reclosing technique and tested for the three different DG technologies: namely the synchronous generator, the asynchronous generator, and the power electronics, by using EMTP.

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

REFERENCES

[1] L. K. Kumpulainen and K. T. Kauhaniemi, "Analysis of impact of distributed generation on automatic reclosing," *Proc. of IEEE Power Engineering Society Winter Meeting*, vol. 1. pp 603-608, 2004.

[2] "IEEE Guide for Automatic Reclosing of Line Circuit Breakers for AC Distribution and Transmission Lines," *IEEE Power Engineering Society*.

[3] S. P. Ahn, C. H. Kim, R. K. Aggarwal, and A. T. Johns, "An alternative approach to adaptive single pole auto-reclosing in high voltage transmission systems based on variable dead time control," *IEEE Trans. on Power Delivery*, vol. 16, no. 4, pp. 667-677, 2001.

[4] S. P. Ahn, C. H. Kim, N. O. Park, H. J. Ju, and E. B. Shim, "The adequacy analysis for installation of high speed grounding switches on the Korean 765kV single transmission line," *KIEE J. Electr. Eng. Technol.*, vol. 1, no. 4, pp. 427-434, 2006.

[5] "Alternative Transients Program ATP Rule Book," *EEUG, Canadian/American EMTP User Group*.

[6] S. M. Yeo and C. H. Kim, "Analysis of system impact of the distributed generation using EMTP with particular reference to protection strategies," *Proc. of IFAC Symposium on Power Plants & Power System Control*, Korea, pp. 897-902, Sep. 2003.

[7] J. G. Slootweg, *Wind Power Modelling and Impact on Power System Dynamics*, Doctor's Thesis, Delft University of Technology, The Netherland, 2003.

[8] "Modelling New Forms Of Generation And Storage," *CIGRE Task Force 38.01.10*, November, 2000.

[9] F. V. Edwards, G. J. W. Dudgeon, J. R. McDonald, and W. E. Leithead, "Dynamics of distributed networks with distributed generation," *Proc. of IEEE Power Engineering Society Summer Meeting*, vol. 2, pp. 1032-1037, 2000.

[10] J. G. Slootweg and W. L. Kling, "Impacts of distributed generation on power system transient stability," *Proc. of IEEE Power Engineering Society Summer Meeeting*, vol. 2, pp. 862-867, 2002.

[11] M. Reza, P. H. Schavemaker, J. G. Slootweg, W. L. Kling, and L. van der Sluis, "Impacts of distributed generation penetration levels on power systems transient stability," *Proc. of IEEE Power Engineering Society General Meeting*, vol. 2, pp. 2150-2155, 2004.

[12] A. M. Azmy and I. Erlich, "Impact of distributed generation on the stability of electrical power systems," *Proc. of IEEE Power Engineering Society General Meeting*, vol. 2, pp. 1056-1063, 2005.

[13] S. I. Jang, M. C. Shin, C. D. Yoon, and R. C. Campbell, "A study on adaptive autoreclosure scheme with real-time transient stability", *KIEE J. Electr. Eng. Technol.*, vol. 1, no. 1, pp. 8-15, 2006.

[14] L. Y. Qun, Tenglin, L.W. Shun, and L. J. Fei, "The study on real-time transient stability emergency control in power system," *Proc. of IEEE CCECE Canadian Conf.*, vol. 1, pp. 138-143, 2002.

[15] B. H. Zhang, Y. C. Yuan, and Z. Chen, "Computation of optimal reclosure time for transmission lines," *IEEE Trans. on Power Systems*, vol. 17, no. 3, pp. 670-675, 2002.

Hun-Chul Seo was born in Korea, 1982. He received the B.S. and M.S. degrees in Electronic Engineering from Sungkyunkwan University, Ko-rea, 2004 and 2006 respectively. He is currently working toward a Ph.D. degree at Sungkyunkwan University. His research interests include power system transients, protection and power system stability.

Chul-Hwan Kim was born in Korea, 1961. In 1990 he joined Cheju National University, Cheju, Korea, as a Full-time Lecturer. He has been a visiting academic at the university of BATH, UK, in 1996, 1998, and 1999. Since March 1992, he has been a Professor in the School of Electrical and Computer Engineering, Sungkyunkwan University, Korea. His research interests include power system protection, artificial intelligence application for protection and control, the modeling /protection of underground cable and EMTP software. He received the B.S. and M.S. degrees in Electrical Engineering from Sungkyunkwan University, Korea, 1982 and 1984, respectively. He received the Ph.D. in Electrical Engineering from Sungkyunkwan University in 1990. Currently, he is a Director of Center for Power IT (CPIT) in Sungkyunkwan University.