KIEE International Transactions on Power Engineering, Vol. 5-A, No. 4, pp. 357~365, 2005 **357**

An Adaptive Setting Method for the Overcurrent Relay of Distribution Feeders Considering the Interconnected Distributed Generations

Sung-Il Jang[†] , Kwang-Ho Kim*, Yong-Up Park*, Jung-Hwan Choi, Yong-Cheol Kang***, Sang-Hee Kang[§], Seung-Jae Lee[§], Hideharu Oshida[§§] and Jong-Keun Park[§§§]**

Abstract - This research investigates the influences of distributed generations (DG), which are interconnected to the bus by the dedicated lines, on the overcurrent relays (OCR) of the neighboring distribution feeders and also proposes a novel method to reduce the negative effects on the feeder protection. Due to the grid connected DG, the entire short-circuit capacity of the distribution networks increases, which may raise the current of the distribution feeder during normal operations as well as fault conditions. In particular, during the switching period for loop operation, the current level of the distribution feeder can be larger than the pickup value for the fault of the feeder's OCR, thereby causing the OCR to perform a mal-operation. This paper proposes the adaptive setting algorithm for the OCR of the distribution feeders having the neighboring dedicated feeders for the DG to prevent the mal-operations of the OCR under normal conditions. The proposed method changes the pickup value of the OCR by adapting the power output of the DG monitored at the relaying point in the distribution network. We tested the proposed method with the actual distribution network model of the Hoenggye substation at the Korea Electric Power Co., which is composed of five feeders supplying the power to network loads and two dedicated feeders for the wind turbine generators. The simulation results demonstrate that the proposed adaptive protection method could enhance the conventional OCR of the distribution feeders with the neighboring dedicated lines for the DG.

Keywords: Adaptive relaying, DG, OCR

1. Introduction

As one of the better alternatives to solving environmental problems and to coping with rising energy prices and power plant construction costs, distributed generations (DG) including photovoltaic, wind turbines, fuel cells, micro-sized turbines, and internal combustion engine-generators are expected to play an important role in the near future. The DG may make a contribution to improve the quality of power, minimize peak loads, and eliminate the need for reserve margin [1, 2]. The majority of DGs are connected with distribution networks. They may make significant impacts on distribution system operation, protection, and control with respect to the voltage regulation, voltage flicker, harmonics, fault current levels, the losses of the network, and etc. [1-6]. Thus, the impacts from interconnection of the DGs should be accurately assessed and mitigated.

One of the major problems encountered in interconnecttion of the DG occurs during the stage of loop operation. In a loop scheme, two distribution feeders are tied together by a normally opened switch, so that, in case of repairing or installing an electric device on one circuit, a load can be transferred temporarily from one to the other. Such operation can improve reliability and maintain service continuity to the customers. However, the current of the distribution feeder interconnected with the DG may increase abruptly in the loop operation because the short-circuit capacity of the distribution network will increase due to the grid connected DG. A conventional protective system responds to faults or abnormal events in a fixed predetermined manner. Thus, during the switching periods for that loop operation, the current magnitude of the distribution line in the substation with a DG can be larger than the pickup value for the fault of the feeder's OCR; therefore, the OCR can perform a mal-operation. These impacts of the DG on the OCR may be varied in direct proportion to its generating power [7-9]. Therefore, it

---

[†] Corresponding Author: HANKOOK IED Co., Seoul, Korea (sijang@chonbuk.ac.kr)
[*] Department of Electrical and Computer Engineering, Kangwon National University, Chuncheon Korea (khokim@kangwon.ac.kr, upup22@hanmail.net)
[**] Taegwang E&C, Anyang, Korea (elecjhchoi@tge.co.kr)
[***] Division of Electronics and Information Engineering, Chonbuk National University, Chonju Korea (yckang@chonbuk.ac.kr)
[§] Department of Electrical Engineering, Myongji University, Yongin Korea (shkang@mju.ac.kr, sjlee@mju.ac.kr)
[§§] Mitsubishi Electric Corporation, Japan (Oshida.Hideharu@dh.MitsubishiElectric.co.jp)
[§§§] School of Electrical Engineering, Seoul National University, Seoul Korea (parkjk@snu.ac.kr)
Received April 13, 2005 ; Accepted September 22, 2005

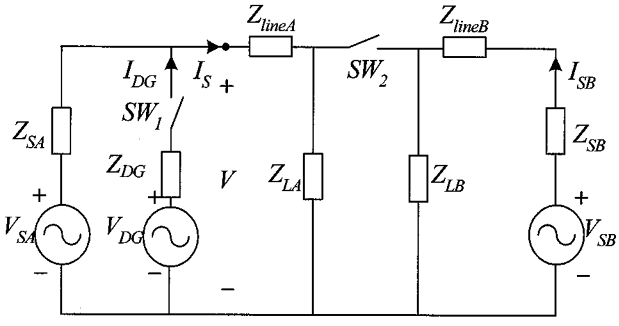
should be necessary to consider the influences of the DG's power for preventing the mal-operation of protective devices during normal conditions.

This paper presents a novel adaptive relaying algorithm of the OCR applied in the distribution feeders to solve the negative influences of the DG on distribution networks. The proposed method is based on the increase/decrease of short-circuit capacity due to the contribution of the DG. The method changes the pickup value of the OCR adapting the power of the DG. According to the increase or decrease of the DG's power, the method varies the pickup value of the OCR applied in distribution lines. We tested the proposed method on the Hoenggye substation of the Korea Electric Power Corporation (KEPCO) with wind turbine generators. The simulation results show that the proposed method reflecting the power output of the DG enhances the protective functions for the OCR compared with conventional ones and particularly prevents mal-operation of the circuit breaker during loop operations.

2. The adaptive relaying method for OCRs considering the power of the DGs

In this section, we will investigate the effect of the power of the DG on the current in the relaying point and describe the proposed method considering their power and the network load conditions.

2.1 Effect of DG's output on the short-circuit capacity of utility networks and the current in the loop operation



V_{SA}, V_{SB}, V_{DG}: Voltages of utility and DG
V: Voltage of the relaying point
Z_{SA}, Z_{SB}, Z_{DG}: Source impedances of utility and DG
Z_{lineA}, Z_{lineB}, Z_{LA}, Z_{LB}: Impedances of the line and the load
I_{SB}, I_{DG}: Currents of utility and DG
I_S: Current of the relaying point
SW_1, SW_2: Switches

Fig. 1 Simplified equivalent circuit of distribution lines including DG

In this subsection, we investigate the effect of the DG on the short-circuit capacity of the grid and the current magnitude in the loop operation. If the DG supplies the power to the distribution network, the source impedance of the utility networks will decrease. Fig. 1 shows a simplified equivalent circuit of distribution networks including the DG.

Before the DG is connected to the utility networks, when the SW is closed, the current at the relaying point and utility current, I_S and I_{SB} might be much varied by the differences between the line impedances, Z_{lineA} and Z_{lineB}, the source impedances, Z_{SA} and Z_{SB} and the load impedances, Z_{LA} and Z_{LB}. The current I_S can be obtained using the superposition principle. First, the current I_S' with the V_{SB} source set equal to zero is given by:

$$I_S' = \frac{V_{SA}}{Z_{SA} + Z_{lineA} + (Z_{LA} // Z_B)} \tag{1}$$

where $Z_B = Z_{LB}//(Z_{SB}+Z_{lineB})$.

Secondly, set the V_{SA} source to zero. The current I_s'' is obtained by:

$$I_S'' = -I_{SB} \frac{Z_L}{Z_L + Z_{SA} + Z_{lineA}} \tag{2}$$

where $Z_L = Z_{LA}//Z_{LB}$.

If we rewrite (2) with V_{SB}, the I_s'' is expressed by:

$$I_S'' = -\frac{V_{SB}}{(Z_A // Z_{LB}) + Z_{lineB} + Z_{SB}} \times \frac{Z_L}{Z_L + Z_{SA} + Z_{lineA}} \tag{3}$$

where $Z_A = Z_{LA}//(Z_{SA}+Z_{lineA})$.

Finally the total current I_S is calculated by adding (3) to (1) i.e.:

$$I_S = \frac{V_{SA}}{Z_{SA} + Z_{lineA} + (Z_{LA} // Z_B)} - \frac{V_{SB}}{(Z_A // Z_{LB}) + Z_{lineB} + Z_{SB}} \times \frac{Z_L}{Z_L + Z_{SA} + Z_{lineA}} \tag{4}$$

After the DG is connected to the utility network by closing the SW_1, by assuming the V_{DG} with the V_{SA}, the current at the relaying point, I_s can be expressed by:

$$I_S = \frac{V_{SA}}{Z_{SA(DG)} + Z_{lineA} + (Z_{LA} // Z_B)} - \frac{V_{SB}}{(Z_{A(DG)} // Z_{LB}) + Z_{lineB} + Z_{SB}} \times \frac{Z_L}{Z_L + Z_{SA(DG)} + Z_{lineA}} \tag{5}$$

where $Z_{SA(DG)}=Z_{SA}//Z_{DG}$ and $Z_{A(DG)}=Z_{LA}//(Z_{SA(DG)}+Z_{lineA})$. In this paper, we can calculate the source impedance of the

DG, Z_{DG} using voltage and current monitored at the relaying point of the power line with the DG. It is the equivalent source impedance of the DG, which contains the line impedance of the dedicated power line with the DG.

Consequently, the increment of the relaying current ΔI_S due to the DG can be obtained by subtracting (5) from (4).

$$\Delta I_S = V_{SA}\left[\frac{1}{Z_{SA(DG)}+Z_{lineA}+(Z_{LA}//Z_B)} - \frac{1}{Z_{SA}+Z_{lineA}+(Z_{LA}//Z_B)}\right] - V_{SB}Z_L \times\left[\frac{1}{\{(Z_{A(DG)}//Z_{LB})+Z_{lineB}+Z_{SB}\}(Z_L+Z_{SA(DG)}+Z_{lineA})} - \frac{1}{\{(Z_A//Z_{LB})+Z_{lineB}+Z_{SB}\}(Z_L+Z_{SA}+Z_{lineA})}\right] \quad (6)$$

We will investigate the effect of the DG on the current in the loop operation with (6) when the Z_{LA} is changed from zero to maximum load (10 MVA) and the output of the DG is changed from 0% to 100% of the rated power (45 MVA). The data for simulating the distribution network and DG are presented in the Appendix. Fig. 2 gives the results for contribution of the DG to the current in the loop operation. To show the influence of load in the other network on I_S, we assume the Z_{LB} with 5 MVA (Case I) and 10 MVA (Case II), respectively. The reduced $Z_{SA(DG)}$ due to the contribution of DG, which means large short-circuit capacity of distribution networks, magnifies the relaying current, I_S in comparison with that of the network having a large source impedance. As shown in Fig. 2, if the capacity of the DG is large, the conventional OCR may frequently mal-operate the circuit breaker during the loop operation. The I_S can be increased with a higher level in case the interconnected and the other network are heavy loaded.

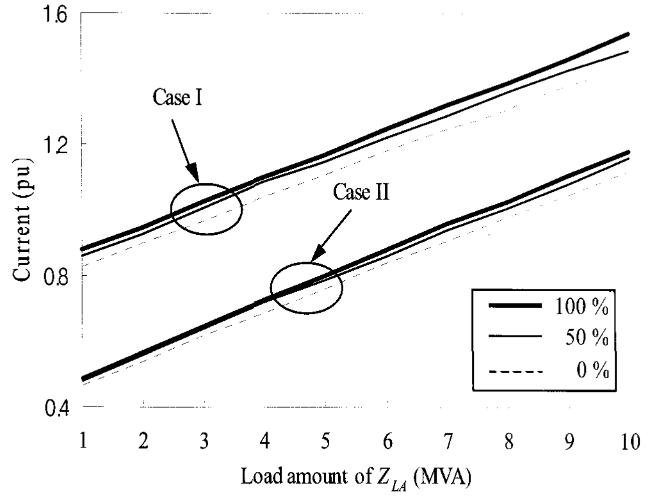


Fig. 2 The current, I_S in the loop operation of distribution network to which the DG is connected, where the generating power output of the DG is assumed 0%, 50%, and 100% of rated power

2.2 Effect of DG's output on the fault level

This part describes the influences of the DG on the distribution fault current. As mentioned in the previous section, the source impedance, $Z_{SA(DG)}$ of the distribution network with the DG is decreased in proportion to the power of the DG, which magnifies the fault current magnitude at the relaying point.

Before the DG is connected to the grid and the SW_2 is opened, the current at the relaying point for a three phase ground fault in the end of power line, I_F is given by:

$$I_F = \frac{V_{SA}}{Z_{SA} + Z_{lineA}} \quad (7)$$

After the DG is connected into the grid by closing the SW_1, the fault current at the relaying point, I_F can be expressed by:

$$I_F = \frac{V_{SA}}{Z_{SA(DG)} + Z_{lineA}} \quad (8)$$

Consequently, the increment of the relaying fault current ΔI_F due to the DG can be obtained by subtracting (8) from (7).

$$\Delta I_F = V_{SA}\left(\frac{1}{Z_{SA(DG)} + Z_{lineA}} - \frac{1}{Z_{SA} + Z_{lineA}}\right) \quad (9)$$

The reduced $Z_{SA(DG)}$ due to the contribution of the DG will magnify the I_F and it will be varied according to the power of the DG with (9). However, though the $Z_{SA(DG)}$ decreases, if the fault occurs at the point far from the bus or has a high fault impedance, the current may not increase much because of line or fault impedance.

2.3 Proposed adaptive overcurrent relaying method

Once in a while, during the network operation of the distribution system, the line current can be greater than the pickup value of the OCR, 1.5 pu even without the DG. Moreover, in these situations, integrating the DG may increase the possibility for mal-operation of the OCR since it usually reduces the source impedance as described in the previous section. To avoid this negative effect on the OCR in distribution feeder, in this paper, we propose the adaptive relaying algorithm for the OCR applied in the distribution feeder considering the power of the DG.

This paper proposed the adaptive relaying method for the OCR considering the integration of the DG as in (10).

$$I_{set(new)} = 1.5 + \Delta I_S / I_{rated} \quad (10)$$

where the $I_{set(new)}$ is the adaptively changed pickup value for the OCR of the feeder. The ΔI_S and I_{rated} are the incremental currents due to the contribution of the DG and rated current of distributed lines, respectively. The ΔI_S can be calculated with (6), which is a varied condition of load amount, distribution line and power of the DG. As the power of the DG increases, the $Z_{SA(DG)}$ decreases. Thus, the $I_{set(new)}$ can be changed by the DG's power, adaptively. In this paper, the proposed method didn't change the time-current curves (TCC) of the OCR to maintain the coordination between protective devices in distribution networks.

Fig. 3 represents the flow diagram for the proposed adaptive relaying method. First, the proposed method calculates the source impedance of the DG, Z_{DG} with voltage and current monitored at the relaying point of the dedicated line having the DG using Thevenin's theorem. The equivalent source impedance, $Z_{SA(DG)}$ is calculated with Z_{SA} and Z_{DG}. And then, the proposed method changes the pickup value of the OCR with (10). The Z_{LB} is assumed with 10 MVA to consider the largest load amount in the other network. We change the pickup value of the OCR with $I_{set(new)}$ in case the load, Z_{LA} is larger than 5 MVA. We divide the power lines in the distribution network with the DG into three groups. One is a feeder having network loads without the DG. Another is a feeder with the DG as well as network loads. The third is a dedicated line for the DG without network load. If the feeder has the DG as well as network loads, we can distinguish whether the power of the DG is bigger than the load or not by monitoring the direction of the current. If the output of the DG is larger than the load, we calculate the equivalent source impedance just as the dedicated line with the DG.

Generally, the pickup value of the OCR, 1.5 pu is chosen considering the network conditions. Though the amount of load is light, the OCR must detect the fault in the end of the line without the dead zone of protection, where the fault is assumed with high impedance fault having 30 Ω. The mal-operation of the OCR in the loop operation may be occurred in the heavy load as shown in Fig. 2. Thus, though a grid connected with the DG adopts the proposed method for protecting their networks, the OCR can detect the fault regardless of the power of the DG, correctly. Moreover, it may prevent the mal-operation of protective devices for normal conditions, considerably.

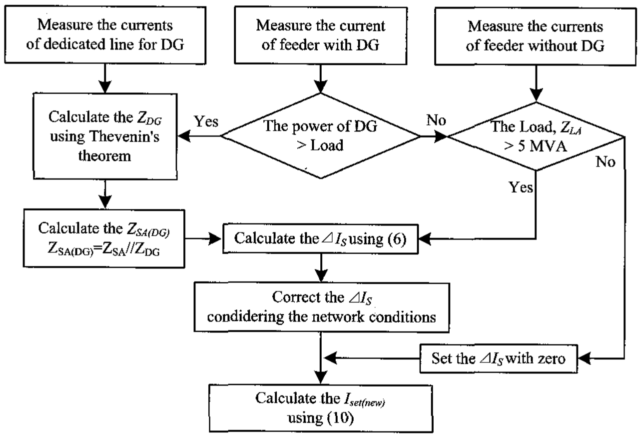


Fig. 3 Flow diagram of the proposed adaptive overcurrent relaying method

3. Case Study

We tested the proposed adaptive relaying algorithm for the OCR of the distribution feeders including not only the loop operations, but also the fault conditions to show the feasibility of the proposed adaptive method by varying the generating power of the DG.

3.1 Modeling of distribution networks having DG

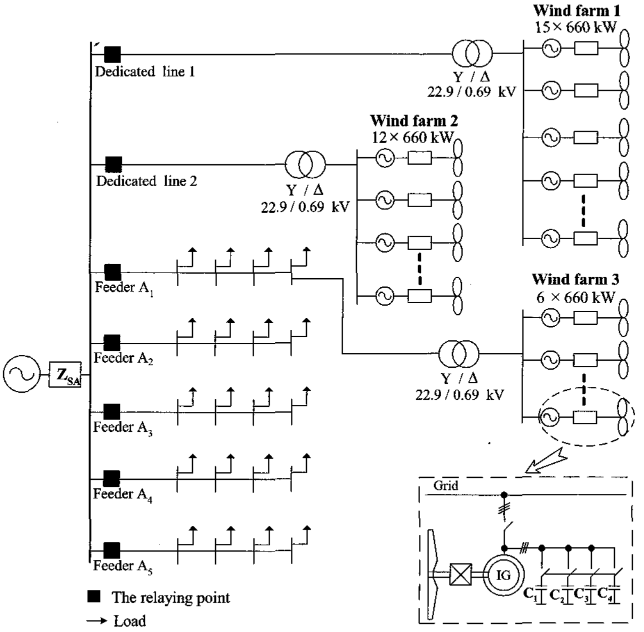


Fig. 4 Hoenggye distribution networks model with DG

In this paper, by using PSCAD/EMTDC, we model the Hoenggye distribution networks of KEPCO, which are composed of five feeders for loads and two dedicated lines for the DG as shown in Figs. 4 and 5 [10]. We assumed the DG with three kinds of wind farms composed of the 660 kW wound-rotor type induction wind turbine generators. Two of the wind farms are interconnected with the distribution network by the ACSR 160 mm^2 dedicated line because of the large generating capacity. Another one is interconnected to the Feeder A_1 with the system loads. The 690/22900 V step-up transformers with an impedance of 1% are assumed in the wind farm. The 4-step capacitor banks are installed in front of the wind turbine generator to compensate for the reactive power consumed by the induction generators [11, 12]. The technical data for distribution networks and the induction generator used in the simulation are provided in Appendix [13]. The set values of overcurrent relay used in the Hoenggye distribution feeders are represented in the Appendix. In this Table, 51 signifies overcurrent relay and *VI* is very inverse, which is a characteristic type for the operating time of the protective relay.

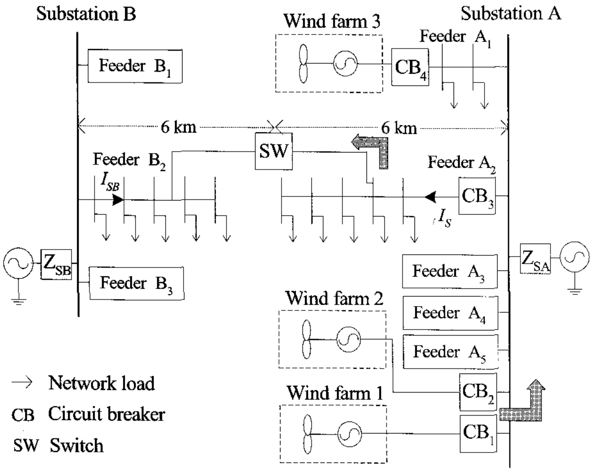


Fig. 5 Distribution networks model for loop operations

3.2 The adaptive relaying pickup value of the OCR according to the power of the DG

This subsection describes the adaptive pickup value of the OCR according to the generating outputs of wind farms to solve the negative effect of the DG. In the distribution network model of Fig. 4, we increase the power of the wind farm from zero to rated power. As the power of the wind farm increases, the new set value, $I_{set(new)}$ of protective relay increases as shown in Fig. 6. The $I_{set(new)}$ increases with 1.67 pu when the Z_{LA} is 10 MVA and the power output of the wind farm is 100% of rated power. Thus, the proposed adaptive relaying algorithm can change the set value of the OCR considering the power of the DG.

3.3 The performance tests of the proposed method

3.3.1 Loop operation conditions

At first we made a typical loop operation case of the distribution network without wind farm as in Fig. 5 by closing the *SW* at 3 sec. As shown in Fig. 7, the I_S abruptly increased after closing the *SW* due to the variations of allotted network loads caused by the differences between the short-circuit capacity of distribution A and B. In this circuit model, the short-circuit capacity of substation A is somewhat larger than that of substation B as shown in the Appendix, while the Z_{lineA} from substation A to *SW* is the same as the Z_{lineB} of Feeder B$_2$ from substation B to *SW*. Although the I_s increases with 1.37 pu, it doesn't exceed the pickup value of the OCR referred to in Table 4, 1.5 pu, which isn't considered by fault condition.

Next, we made other loop operation cases of the distribution network having wind farm with the same network conditions as in the above case. In this case, we assumed the power of wind farm with 50% and 100% of the rated power, respectively. After closing *SW* the I_S increases larger than that of the previous case without wind farm due to the reduced source impedance as shown in Fig. 8. The reduced source impedance may magnify short-circuit capacity of the distribution network with the DG, thus the I_S increases too. The I_S increases with 1.51 pu and 1.59 pu in case the power of wind farm is 50% and 100% of rated power, respectively. Because the I_S is larger than the conventional set value of the OCR, 1.5 pu, if we adopt the conventional TCC of the OCR referred to in the Appendix, the OCR generates the trip signal after preset delay time. This phenomenon can occur more frequently as the power of the wind farm increases. It is necessary to prevent the mal-operation of protective devices by considering the power of the wind farm.

Finally, we adopted the proposed adaptive relaying algorithm of the OCR for loop operation of distribution networks to solve the negative effect of the DG. The network conditions are identical to those of the second case. Though the wind farm supplies power to the distribution network, the proposed adaptive relaying algorithm prevents the mal-operation of the OCR by substituting the set value, 1.5 pu with $I_{set(new)}$ that reflects the generating output of the wind farms. Figs. 9 and 10 indicate simulation results for loop operation in case of 50% and 100% of the rated power of the wind farms, respectively. The $I_{set(new)}$ is 1.56 pu and 1.64 pu.

3.3.2 Distribution line fault conditions

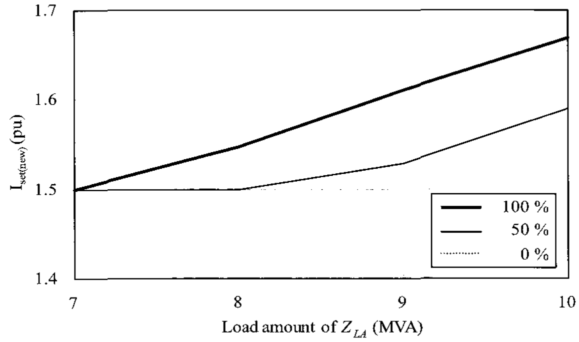


Fig. 6 The adaptive pickup value of the OCR, $I_{set(new)}$ in the Feeder A$_2$ considering the power of the DG and load amount of Z_{LA}, where the generating power output of the DG is assumed with 0%, 50%, and 100% of rated power

We also tested the proposed method with distribution line faults such as a single line to ground and high impedance fault to verify whether the adaptively changed set value has a negative effect on the protection performance of the OCR.

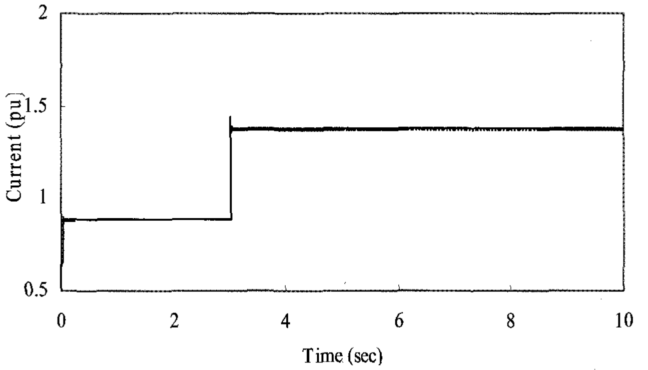


Fig. 7 The simulation result for loop operation of the distribution network to which the wind farm isn't connected

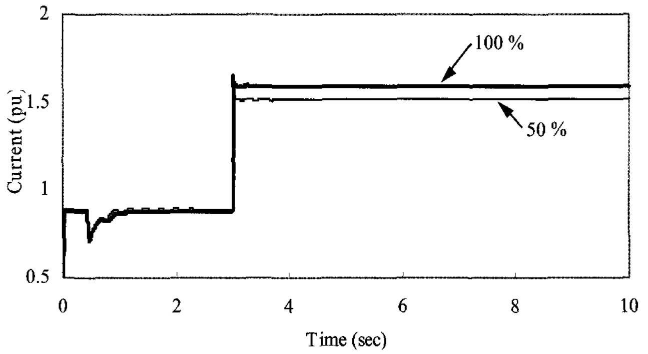


Fig. 8 The simulation result for loop operation of the distribution network to which the wind farm is connected, where the generating power output of the wind farm is 50% and 100% of rated power, respectively

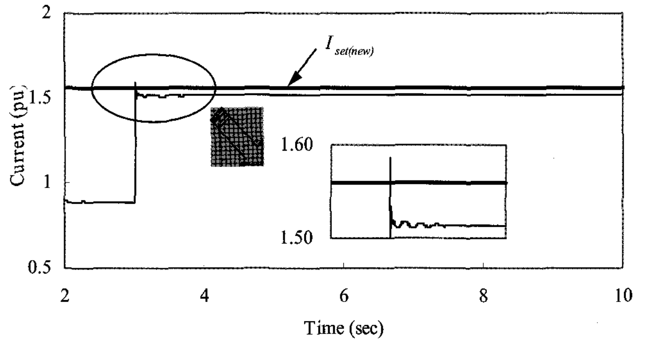


Fig. 9 The simulation result for loop operation of the distribution network to which the wind farm is connected by adopting the proposed adaptive relaying method for the OCR, where the generating power output of the wind farm is 50% of rated power

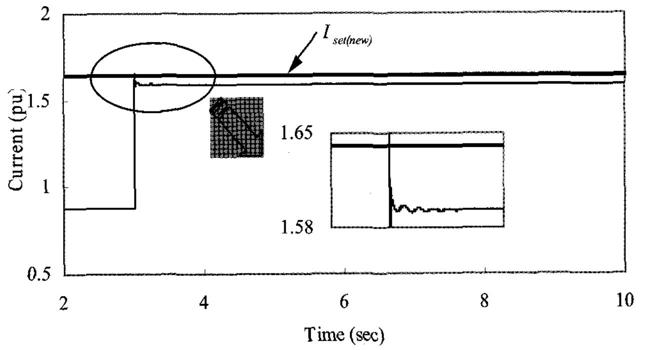


Fig. 10 The simulation result for loop operation of the distribution network to which the wind farm is connected by adopting the proposed adaptive relaying method for the OCR, where the generating power output of the wind farm is 100% of rated power

1) A single line to ground fault

For this case, we simulated a single line to ground fault at 22 km in the Feeder A_2, where the output of the wind farm is 0%, 50% and 100% of rated power. The simulation results are shown in Fig. 11. The fault current abruptly increases with 3.18 pu, 3.20 pu and 3.21 pu according to the power of the DG, respectively. They are larger than the pickup value of the OCR, 1.5 pu, 1.56 pu and 1.64 pu, which are newly indicated in the proposed method. The test results show that the proposed algorithm does not deteriorate the capability of the OCR for fault detection, even though the set value is increased due to the generating power of the wind farm.

2) High impedance fault

We simulated high impedance faults on the same fault location of the single line to ground fault by varying the generating power of the wind farms with 0%, 50% and 100%. For these cases, we assumed the fault impedance as 30 Ω, since this value is fixed as the lowest fault impedance that the OCR has to detect in Korea. The I_S increased with 1.94 ~ 1.96 pu according to the power of the DG as shown in Fig. 12. However, their variations are small regardless of the power of the wind farm. These characteristics can be explained with (9) by inserting the fault impedance into its denominator. We can detect such a fault by adopting the proposed adaptive OCR relaying algorithm.

5. Conclusion

This paper introduced grid integration of wind turbine generators and their impacts on utility protection relay and proposed the adaptive algorithm for the OCR in distribution feeders to solve the negative influences of the

DG. The proposed method changes the pickup value of the OCR adapting the power output of the DG monitored at the relaying point in the distribution network. If the power of the DG is increased or decreased, then the set values of the OCR are varied in direct proportion to their power. We tested the proposed method using several distribution network conditions including not only loop operation conditions, but also fault conditions such as single line to ground and high impedance fault. The test results showed that the proposed algorithm is capable of preventing the mal-operation of circuit breakers resulting from the insertion of the DG for loop operation and detecting the fault conditions. Therefore, the results verify that the proposed method can be efficiently implemented in actual protective devices and is able to improve their performance.

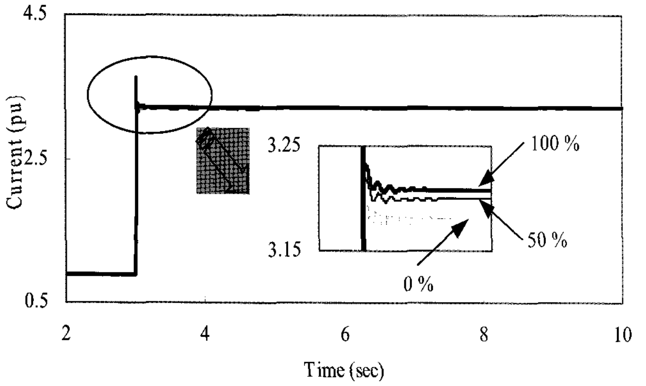


Fig. 11 The simulation result for a single line to ground fault in the distribution network with wind farm, where the generating power of the wind farm is 0%, 50% and 100% of rated power, respectively

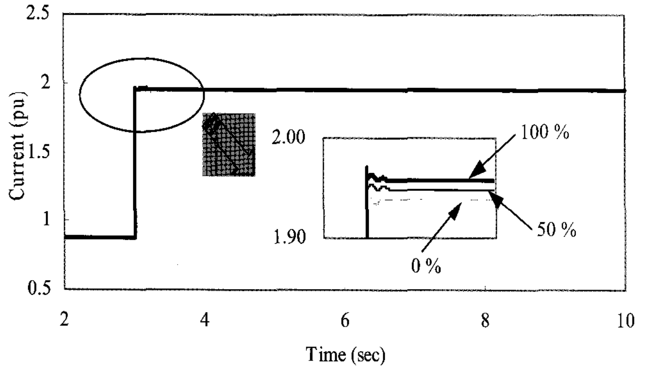


Fig. 12 The simulation result for high impedance faults in the distribution network with wind farm, where the generating power output of the wind farm is 0%, 50% and 100% of rated power, respectively

Appendix

This appendix provides the technical data used in this paper

Table 1 The Line Data for Simplified Equivalent Circuit having DG

Details	Distribution Networks
Voltages of utility and DG	13.2 kV
Short circuit capacity of utility A	70 MVA
Short circuit capacity of utility B	50 MVA
Generating capacity of DG	45 MVA
Line impedance of Z_{lineA}	1.24+2.63 Ω
Line impedance of Z_{lineB}	4.62+9.87 Ω

Table 2 Parameters of the Vestas V47-660 kW induction generator

Details	Wind Turbine
Rating	660 kW
Line to line voltage	690 V
Hz.	60
Pole No.	4
Base power	660 kW
Stator connection	Delta
Stator resistance	0.00393 Ω
Stator reactance	0.060 Ω
Rotor resistance, internal	0.00467 Ω
Rotor res. ext. (2% slip)	0.0070 Ω
Rotor res. ext. (10% slip)	0.06233 Ω
Rotor reactance	0.0067 Ω
Iron loss	0.081 Ω
Magnetizing reactance	3.13 Ω

Table 3 Technical data of distribution networks

Details	Distribution Networks
Rated capacity per feeder	10 MVA
Rated line voltage Rated current	22.9 kV 252 A
Nominal frequency	60 Hz
Line types	Three-phase overhead
Source imp. of substation A (ZSA) Source imp. of substation B (ZSB)	0.027 + j2.25 Ω 0.027 + j3.37 Ω
Line impedance	0.31 + j0.66 Ω/km
Length of Feeder A_1	9.68 km
Feeder A_2	22 km
Feeder A_3	4.75 km
Feeder A_4	31.01 km
Feeder A_5	58.40 km

Length of Feeder B_1	9.41 km
Feeder B_2	6 km
Feeder B_3	7.79 km
Length of dedicated line 1, 2	10 km

Table 4 The load data of distribution networks

Load types	Spot loads All wye connected All constant kW, kvar
Loads in the Feeder A_1	1.0 MVA
Feeder A_2	9.5 MVA
Feeder A_3	1.1 MVA
Feeder A_4	5.1 MVA
Feeder A_5	6.5 MVA
Loads in the Feeder B_1	7.8 MVA
Feeder B_2	9.0 MVA
Feeder B_3	6.5 MVA

Table 5 The time-current characteristics of OCR (51), Curve Type *VI*.

Feeder Name	Time Delay Setting (sec)						Instantaneous (sec)
	150%	300%	500%	700%	1000 %	2000 %	
Feeder A_1	12.15	2.22	1.00	0.68	0.53	-	0.05
Feeder A_2	12.15	2.22	1.00	0.68	0.53	-	
Feeder A_3	12.15	2.22	1.00	0.68	0.53	0.42	
Feeder A_4	10.42	1.90	0.85	0.60	0.45	-	
Feeder A_5	10.42	1.90	0.85	0.60	0.45	-	

Acknowledgements

The work described in this paper was supported by the Next-Generation Power Technology Center of Myongji University in Korea.

References

[1] P. P. Barker, and R. W. de Mello, "Determining the impact of distributed generation on power systems: Part1-Radial distribution systems," IEEE, Power Engineering Society Summer meeting, Vol. 3, pp. 1645-1656, 2000.

[2] Thomas Ackermann, Goran Andersson, Lennart Soder, "Electricity market regulations and their impact on distributed generation," IEEE International Con. on Electric Utility Deregulation and Restructuring and Power Technologies, 2000, City University, London, 4-7, pp. 608 – 613, April 2000.

[3] W. J. S. Rogers, "The parallel operation of a generating plant within a regional electricity company's distribution network," IEE Colloquium on the parallel operation of a generating plant within a public electricity network, Chester, UK, Feb 1991.

[4] Jiang Fan and S. K. Salman, "The effect of integration of wind farms into utility network on voltage control due to the co-ordination of AVC relays," Proc. of the 4th International Con. On Advances in Power System Control, Operation and Management, APSCOM-97, Hong Kong, pp. 260-265, November 1997.

[5] D. T. Rizy, W. T. Jewell, and J. P. Stovall, "Operational and design considerations for electric distribution systems with dispersed storage and generation (DSG)," IEEE Trans. on Power Apparatus and Systems, Vol. PAS-104, No. 10, pp. 2864-2871, October 1985.

[6] Hird C. M., Leite, H., Jenkins N. and Li H., "Network voltage controller for distributed generation," Generation, Transmission and Distribution, IEE Proceedings, Vol. 151, Issue: 2, 2pp. 150-156, March 2004.

[7] Roger C. Dugan and Dwight T. Rizy, "Electric distribution protection problems associated with the interconnection of small, dispersed generation devices," IEEE Trans. on Apparatus and Systems, Vol. PAS-103, No. 6, pp. 1121-1127, June 1984.

[8] H. B-L Lee, S. E. Chase, and R. D. Dugan, "Overvoltage considerations for interconnecting dispersed generators with wye-grounded distribution feeders," IEEE Trans. on Power Apparatus and Systems, pp. 3587-3594, December 1984.

[9] Cooper Power Systems, Electrical distribution system protection, 3d ed. Cooper Industries, 1990.

[10] Manitoba HVDC Research Centre, PSCAD/EMTDC user's manual. Canada, 1986.

[11] Mita-Teknik, "Technical Information - Calibration routine for WP4060 Connection Model," Germany, 1999.

[12] Paresh C. Sen, Principles of Electric Machines and Power Electronics. WILEY, Copyright © 1997.

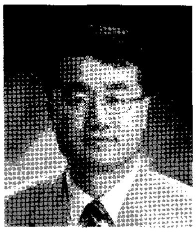
[13] Vestas Wind Systems A/S, Technical report of wind turbine generations, 2001.

Sung-Il Jang
He received his B.S. M.S. and Ph.D. degrees in Electrical Engineering from Kangwon National University, Korea, in 1996, 1998, and 2003, respectively. He is currently with HANKOOK IED Co., Seoul, Korea. His research interests include distributed generation interface with power systems, and adaptive relaying.

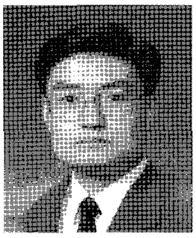
Kwang-Ho Kim
He received his B.S., M.S., and Ph.D. degrees in Electrical Engineering from Seoul National University, Korea, in 1988, 1990, and 1994, respectively. Since 1995, he has been with the Department of Electrical and Computer Engineering, Kangwon National University where he is currently an Associate Professor. His research interests include distributed generation interface with power systems, and power quality analysis.

Yong-Up Park
He received his B.S. degree in Electrical Engineering from Kangwon National University, Korea, in 2005. His research interests are distributed generations (DG) and Microgrids systems.

Jung-Hwan Choi
He received his B.S., M.S. and Ph.D. degrees in Electrical Engineering from Kangwon National University, Korea, in 1997, 1999 and 2004, respectively. He is currently with Taegwang E&C. His research interests are reliability of distribution networks, power quality and distribution planning.

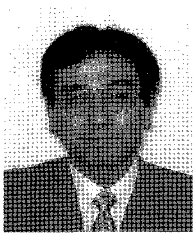


Yong-Cheol Kang
He received his B.S., M.S. and Ph.D. degrees from Seoul National University, Korea in 1991, 1993, and 1997, respectively. He is now an Assistant Professor at Chonbuk National University, Korea. He is also with the Next-Generation Power Technology Center (NPTC), Korea. His main research interest is the development of new protection systems for power systems using digital signal processing techniques.



Sang-Hee Kang
He received his B.S., M.S. and Ph.D. degrees from Seoul National University, Korea in 1985, 1987 and 1993, respectively. He is a Professor at Myongji University, Yongin, Korea. He is also with the Next-Generation Power Technology Center (NPTC), Korea. He was a Visiting Scholar and a Visiting Fellow at the University of Bath, UK in 1991 and 1999. His main research interest is developing digital protection systems for power systems.

Seung-Jae Lee
He received his B.S. and M.S. degrees from Seoul National University, Seoul, Korea, in 1979 and 1981, respectively, and his Ph.D. degree from the University of Washington, Seattle, in 1988. Currently, he is a Professor with the Department of Electrical Engineering at Myongji University, Yongin, Korea. where he has been since 1988. He is also Director of the Next-generation Power Technology Center. His main research areas are protective relaying, distribution automation, and AI applications to power systems



Hideharu Oshida
He received his B.S. and M.S. degrees in electrical eng. from Seikei University in 1979 and 1981 respectively. He received the Ph.D. degree in electrical eng. from Tohoku University in 1998. In 1981, he joined Mitsubishi Electric Corporation. He is currently Engineering Manager of Protection & Control Systems Department. He is principally responsible for development of SPS (Special Protection System). He is a member of IEEJ.

Jong-Keun Park
He received his B.S. degree in electrical engineering from Seoul National University, Korea in 1973 and his M.S. and Ph.D. degrees in electrical engineering from The University of Tokyo, Japan in 1979 and 1982, respectively. From 1983, he has worked as an assistant professor, an associate professor and a professor in the School of Electrical Engineering, Seoul National University, Korea. His research areas are power system economics and energy policy, and power system analysis.