Development of Evaluation Systems for Bi-Directional Protection Coordination in Distribution System Considering Distributed Generations

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Abstract

This paper deals with the optimal evaluation algorithms for bi-directional protection coordination in the case where new distributed generations(DG) are operated in distribution systems. It is very difficult and complicated to handle the interconnection issues for proper bi-directional protection coordination in distribution systems interconnected with DG, because professional skills and enormous amounts of data for the evaluations are required. In order to overcome these problems, the paper proposes reasonable and general evaluation algorithm for bi-directional protection coordination and presents an evaluation system based on the algorithm algorithms and systems using the HMI software. By performing various simulations to practical distribution system with DG, It is verified that the proposed method is practical tool for the fair and objective evaluations systems.

Keywords: *Distributed Generation (DG), Bi-directional protection coordination, Protective devices, Over Current Relay (OCR), Over Current Ground Relay (OCGR)*

1. Introduction

Recently, with the increasing of the interest about global warming, pollutions and so on, a number of distributed generations (DGs) such as photovoltaic (PV) and wind power (WP) can be interconnected with distribution systems. However, the power producers with DG and power company like KEPCO (Korea Electric Power Corporation) have adhered to the existing one way protection coordination method because of the lack of technical skills and experiences. Therefore, it may cause the critical problems due to reverse power flow and change of fault current (e.g. dividing effect) by the DGs [1, 7]. Until now, there are no evaluation systems for protection coordination considering DGs at customer side. Additionally, by increasing the introduction capacity of DGs, the possibility of the protection coordination problems may be getting worse [8, 9]. In order to solve these problems, this paper proposes an evaluation algorithm for bi-directional protection coordination and presents an evaluation system based on the algorithm. Furthermore, this paper simulates various practical distribution systems with DGs. The result shows that the existing method may cause critical problems, and also the effectiveness of proposed method is verified.

2. Evaluation Algorithm for Protection Coordination

2.1. Fault Analysis Algorithm with DG

By increasing the introduction capacity of DGs, the possibility of the protection coordination problems may be getting worse. Therefore, this paper suggests a new evaluation algorithm for protection coordination considering DGs as following steps.

<Step 1> Collecting the data of distribution system and DGs.

<Step 2> Selecting the suitable type of protection devices.

<Step 3> Obtaining the % impedance map of positive and zero sequence, and performing load flow and fault current analysis of distribution system with DGs.

<Step 4> Reviewing the setting values between forward and back-up protection devices.

<Step 5> Checking the TCC (Time-Current Characteristic) curve in order to evaluate the performance of protection coordination whether the operating time difference between forward and back-up protection devices is longer than the guideline value or not.

<Step 6> If the protection coordination is not suitable, adjusting the TCC curve with the change of the time difference.

<Step 7> After the TCC curve is modified, reselecting the proper protection devices if the protection coordination is still not suitable.

<Step 8> Performing the iteration of the above process until the protection coordination is satisfied.

The flowchart of the above algorithm is shown in Figure 1.

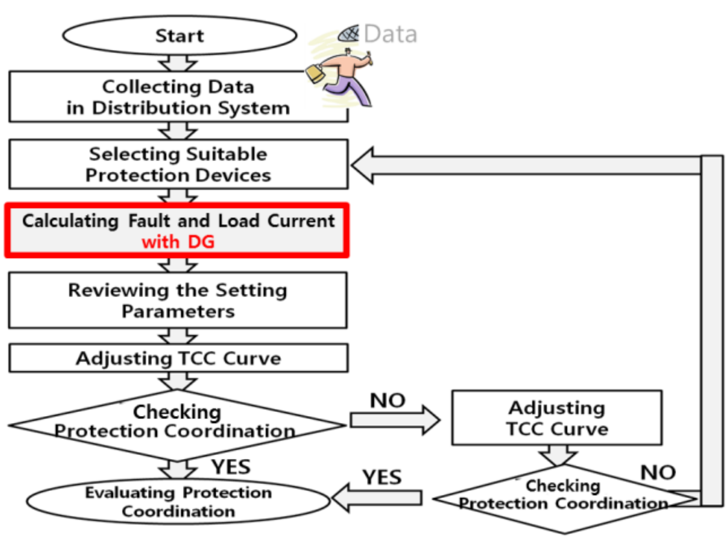

Figure 1. Evaluation Algorithm for Protection Coordination Considering DGs

2.2. Composition of Evaluation System

Figure 2 shows the main menu of the evaluation system for protection coordination based on the presented algorithm in this paper. It has several icons such as S/S (Substation), R/C

(Re-Closer), DG (including customer relay) and so on. This system is made by window-based HMI (Human Machine Interface) program in order to make users comfortable by creating virtual distribution system in an easy manner. The evaluation system can automatically calculate the fault current and voltage profile considering DG, and also evaluate the protection coordination. This program is supposed to be designed for the customer users like DG producers, not power companies.

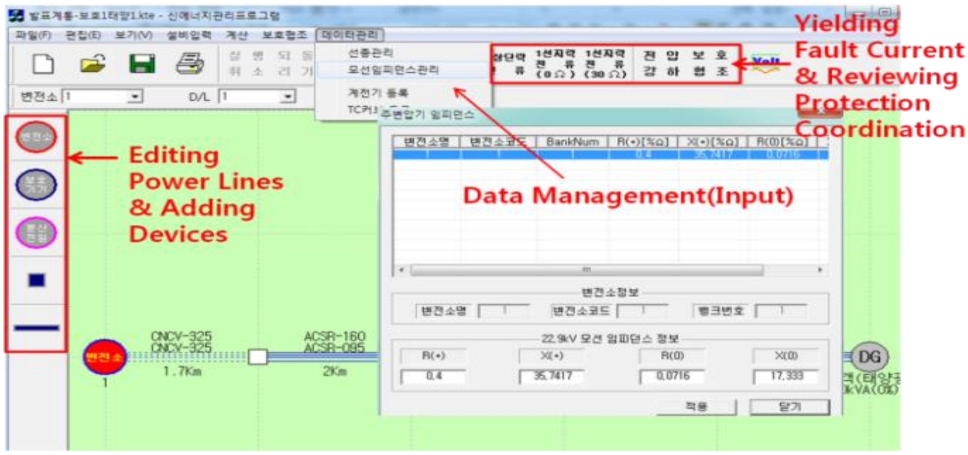

Figure 2. Evaluation System for Protection Coordination

3. Simulation and Analysis

3.1. Modeling of Distribution System with DG

In order to analyze the protection coordination between the power company protection device (re-closer) and customer relay of DG producers, a model distribution system with a wind power system of 3MVA capacity is assumed as shown in Figure 3. In Korea, DG capacity for one feeder is restricted up to 3MVA by government because under 3MVA of DG is proper capacity for practical distribution system. Re-closer location of primary feeder is generally installed at the recommended section which is half of rated load current of a feeder [10, 13]. According to the equation (1), the peak load current (I_{Peak}) is calculated 252A because one primary feeder has 10MVA capacity in normal case.

$$I_{Peak} = \frac{10{,}000[kVA]}{\sqrt{3} \times 22.9[kV]} = 252[A] \qquad (1)$$

Therefore, re-closer is installed at the 126A of load current point. Figure 4 shows the simulation result of model distribution system based on the Figure 3. There is currently no guideline of setting values for relay at customer (power producer) with DG [4, 6]. Therefore, this paper uses the customer's guideline, maximum supply current instead of maximum load current.

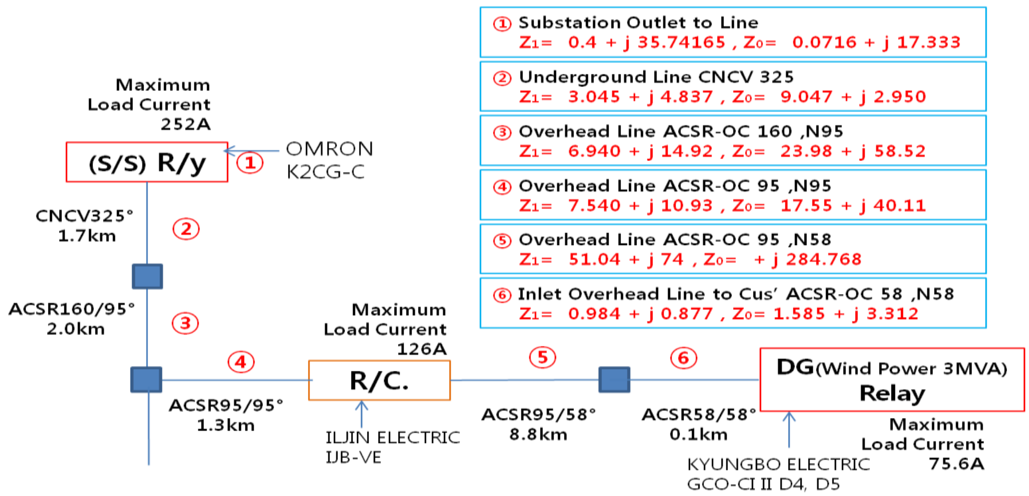

Figure 3. Modeling Distribution System with DG (WP, 3MVA)

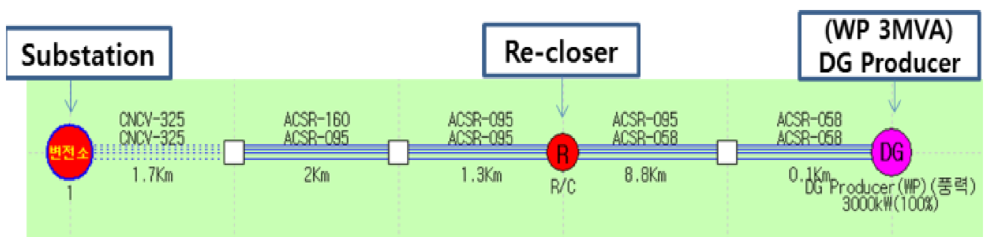

Figure 4. Modeling of Distribution System using the Evaluation System

3.2. Analysis of Protection Coordination

First of all, the fault current should be calculated to obtain the setting values of each protection devices (OCR, OCGR, etc.). Figure 5 is the % impedance map of both positive and zero sequence, in the case where a fault occurs at the customer side of DG. By using this % impedance map, theoretical value of three-phase short circuit current can be obtained by Figure 5.

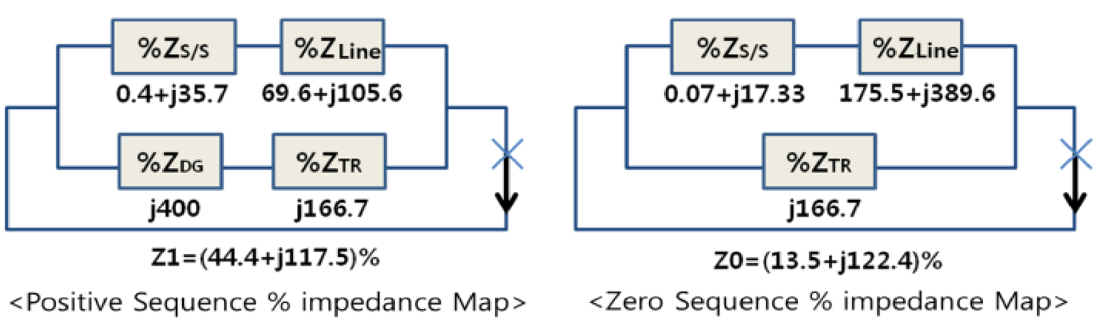

Figure 5. % Impedance Map of Distribution System with DG

Figure 6 shows a simulation result of three-phase short circuit current in the proposed evaluation system. The obtained theoretical value from % impedance map is equal to the simulation result. Therefore, it is confirmed that the evaluation system can automatically calculate the fault current and voltage profile considering DG and also make users comfortable by creating virtual distribution systems in an easy manner.

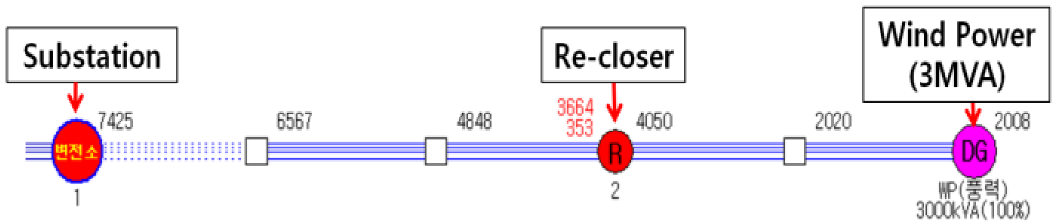

Figure 6. Simulation Result of Three-phase Short Current

Before WP is interconnected, the peak load current at re-closer location is 126A, but after WP is connected, it is reduced to around 50A due to the output of WP, 76A, which is the reverse power flow. Table 1 is re-closer setting values (minimum operation current) recommended by KEPCO guidelines [5]. According to equation (3), the minimum operation current difference between the maximum operation current without WP and minimum operation current with WP is up to 360A.

$$\text{Without DG: } 126A\times2.8 < \text{setting value} < 126A\times4.0$$

$$\text{With DG: } 50A\times2.8<\text{setting value} < 50A\times4.0 \qquad (3)$$

$$(126A\times4.0) – (50A\times2.8) = 364A \fallingdotseq 360A$$

Table 1. Setting Values for Re-closer (Guidelines of KEPCO)

Type		Setting Values
Minimum Operation Current	Phase(OCR)	Over Maximum Load Current × 2.8 Under Maximum Load Current × 4.0
	Ground (OCGR)	Maximum Load Current × 0.3

Figure 7 is a simulation result of operation time of protection devices based on the TCC curve. In this TCC curve, PU (Pick-Up) which means fault current divided by minimum operation current is changed from 16.3 to 20.1 due to WP (DG can affect the operation time of protection devices).

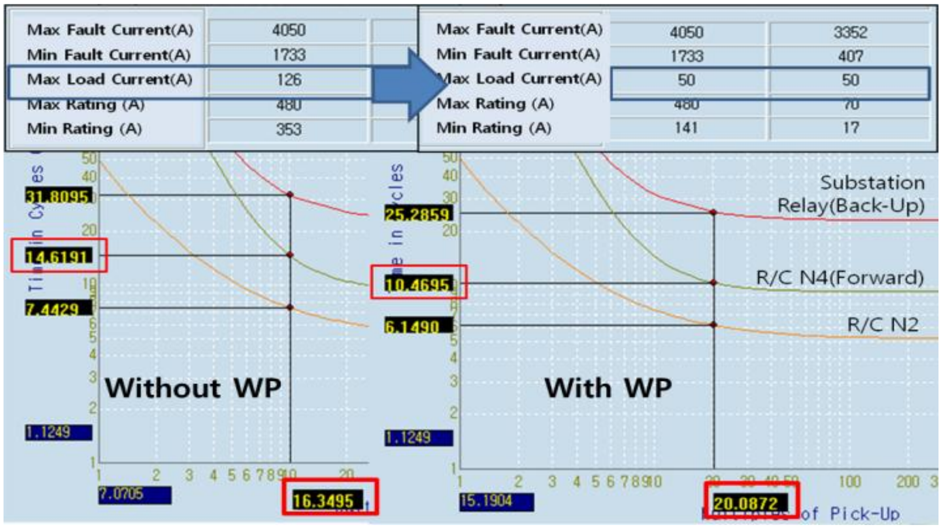

Figure 7. Operation Time Characteristics between S/S Relay and Re-closer without and with WP

Figure 8 shows the operation time characteristics between the re-closer and DG customer's relay, in the case of before and after WP(3MVA).In this simulation, the OCR operation time difference between the re-closer and DG relay are 7.3 and 6.8 cycles. These values are more than 6 cycles (which is guideline value of KEPCO) at 0.5 levers for DG relay. Therefore, the protection coordination problem is not be occurred, in the case where DG is interconnected with distribution system. However, it is found that there are some possibilities to mal-function of protection devices because DG can affect the change of fault current and load current with the increasing of the capacity.

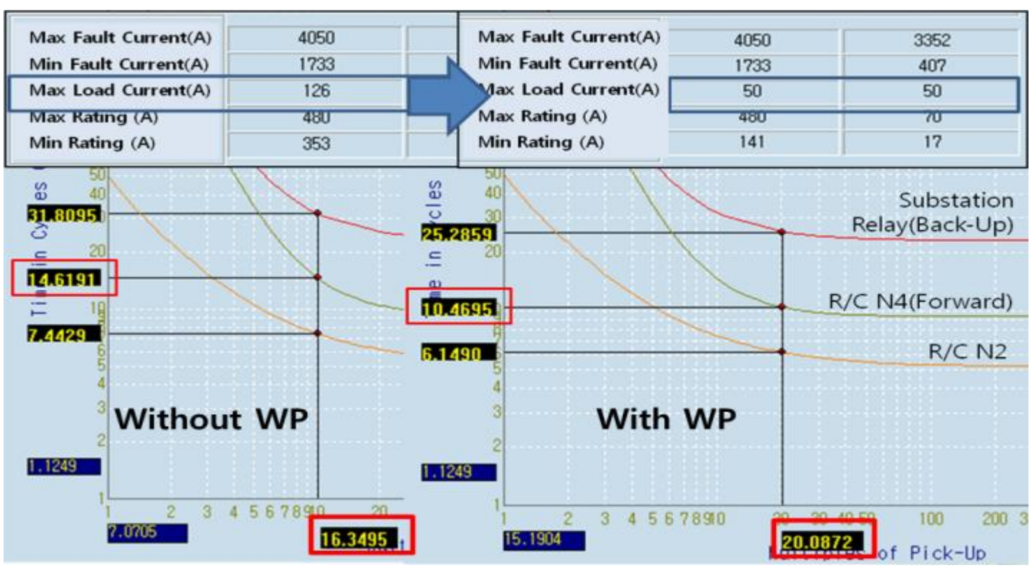

Figure 8. Operation Time Characteristics between Re-closer and DG Relay without and with WP

Table 2. Operation Time Differences of each Protection Devices in the Case without and with WP

Protection Devices \ Capacity of DG		Operation time difference (Cycles)		Coordination operation time (Cycles)
		Without DG	With DG (WP,3MVA)	
S/S -R/C	Phase (OCR)	17.8	17.2	10
	Ground (OCGR)	40	36	10
R/C - DG producer	Phase (OCR)	7.3	6.8	6
	Ground (OCGR)	6.2	6.2	6
S/S - DG producer	Phase (OCR)	20	21.6	17
	Ground (OCGR)	27	30	17

3.3. Modeling of real case

In order to demonstrate whether the proposed algorithm and evaluation system are proper or not, the practical case is assumed [14, 15]. Figure 9 shows the modeling of practical distribution system in “BUK-PYEONG” substation using the proposed evaluation system. As shown in Figure 9, 1MW Photovoltaic (PV) system is located at "BUK-PYEONG" primary feeder, and the connection type of inter-connection transformer is Grounded Wye-delta. It was reported that when "SAM-WHA", "DONG-SAM" and "EO-DAL" primary feeder have problem with a single line ground fault because of external contact, lighting arrestor (LA) damage and burn-out of transformer, the fault currents affected re-closer located at the "BUK-PYEONG" D/L, un-faulted primary feeder to operate through the inter-connection transformer. Like this case, many customers of the primary feeder suffer severe interruption problems. It is called mal-function of protection device.

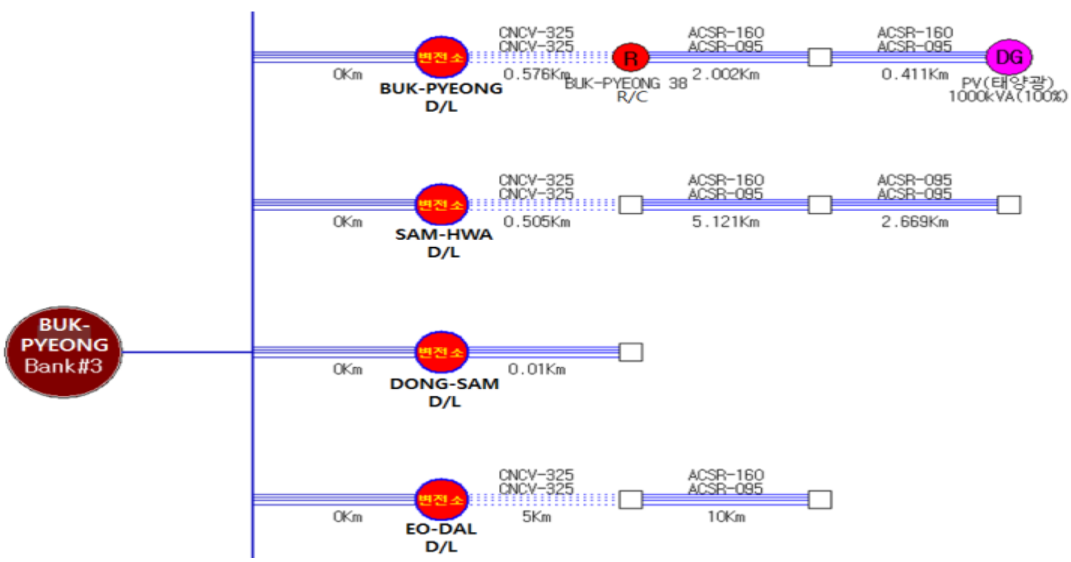

Figure 9. Modeling of Distribution System in “BUK-PYEONG” Substation

Figure 10 shows the simulation result when fault occurred at the end of “SAM-HWA” D/L. In this case, a single line ground fault current is 1,535A and also the fault current flowing through the Grounded Wye-delta connection transformer to the re-closer at “BUK-PYEONG” D/L is 122A. Hence, if the setting value of re-closer OCGR(protection device at

"BUK-PYEONG" D/L, un-faulted primary feeder) is 70A in normal case, OCGR can be operated incorrectly. It is called as mal-function. When operating of protection devices, the color of fault current values is changed to red in the simulation such as Figure 10 and it is checked that the direction of fault current flow.

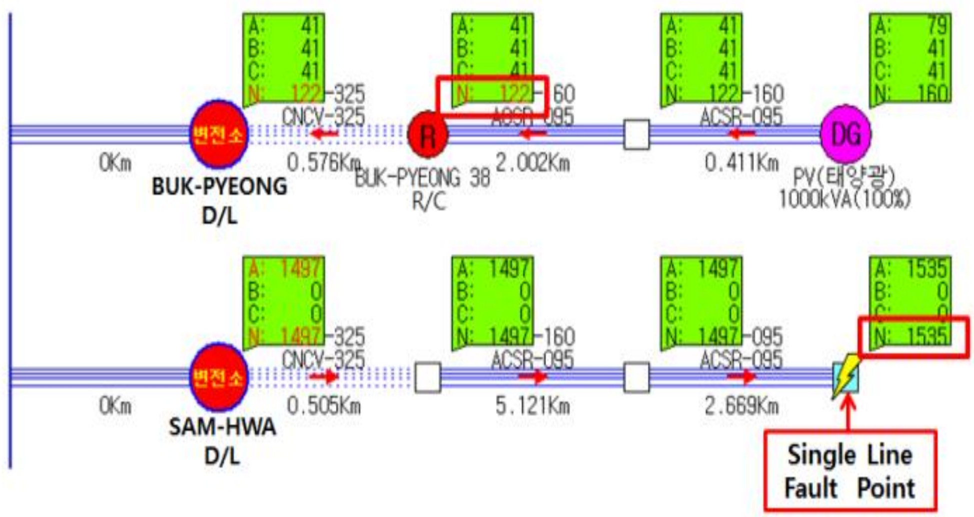

Figure 10. Simulation Result of Single Line Ground Fault

4. Conclusions

There are some possibilities to mal-function of protection devices since DG can make the change of fault current and load current. But, until now there was no evaluation system for evaluating protection coordination, at customer side, considering DGs. Therefore, this paper proposes an evaluation algorithm for bi-directional protection coordination and presents an evaluation system based on the algorithm. From the simulation result, it is verified that the proposed method is one of useful tools for protection coordination analysis when DGs are connected. The results are summarized as follows. It is confirmed that the theoretical value obtained from % impedance map considering DG is equal to the simulation result of proposed method. In the simulation, it is found that DG can make the change of fault current and load current. As a result, PU values are increased and operation time difference of protection devices (between the re-closer and DG customer's relay) is changed from 7.3 to 6.8 cycles by DG. Therefore, it is expected that more capacity of DG can bring more possibility of problems because the cycle clearance is getting shorter with the increasing of DG capacity. Therefore this paper shows the real case that protective device (re-closer, OCGR) is mal-functioned by ground current on N phase flowing through the zero phase sequence path supplied by Grounded Wye-delta connection of DG transformer.

Acknowledgement

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References

[1] Nagpal M, et. al., "Dispersed Generation Interconnection – Utility Prospective", IEEE Trans on Industry Application, vol. 42. No. 3, **(2006)** May.

[2] IEEE 1547.1, "IEEE Standard conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power System", **(2005)** June.

[3] IEEE 1547, "IEEE Standard for Interconnecting Distributed Resources with Electric Power System", **(2003)** July.

[4] "Work procedure and technique guide of interconnection of distributed power of Hokkaido", Japan, **(2002)**.

[5] "Interconnected the technique basis in distribution system of distribution generations", Korea Electric Power Corporation (KEPCO), **(2004)** April.

[6] "Technical system of distribution system of distributed power of Hokkaido", Japan, **(2004)**.

[7] "Tech Spec. of interconnection of Japanese distributed power system" Japan Electrics Organization, **(2001)**.

[8] Arritt RF, Dugan RC, "Distributed generation interconnection transformer and grounding selection", Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, IEEE, **(2008)**, pp. 1 – 7.

[9] Barker PP, de Mello RW, "Determining the impact of distributed generation on power systems: Part 1 - Radial distribution systems", in Proc. IEEE Power Eng. Soc. Summer Meeting, vol. 3, **(2000)**, pp1645-1656.

[10] Jenkins N, Allan R, Crossley P, Kirschen D, Strbac G, "Embedded Generation", London: The Institute of Technical Engineers, **(2000)**

[11] Willis HL, Scott WG, "Distributed Power Generation", New York: Marcel Dekker, Inc., **(2000)**.

[12] HadiSaadat, "Power System Analysis", McGraw-Hill, Printed in Singapore, **(1999)**.

[13] "Guide of technique requisites of interconnection of distribution of Japanese system", Japan, **(1998)**.

[14] Jang MS, Bang HJ, "The Current Status and the Prospects of Wind Energy", Journal of the Environmental Sciences, August, **(2009)**, vol. 18, no. 8, pp. 933-940.

[15] Rho DS, et. al., "A study on protective coordination method in distribution system with new energy sources", Proceedings of the KAIS (The Korea Academia-Industrial Cooperation Society) spring Conference, **(2011)** May, Korea.

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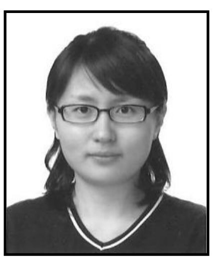

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