Paper accepted for presentation at 2009 IEEE Bucharest Power Tech Conference, June 28th - July 2nd, Bucharest, Romania

Improved Operating Scheme Using an IEC61850-based Distance Relay for Transformer Backup Protection

Hyung-Kyu Kim, *Student Member, IEEE*, Sang-Hee Kang, Soon-Ryul Nam and Sea-Seung Oh, Member*, IEEE,*

***Abstract*—Problems occur when zones overlap in the conventional step distance protection scheme. If the same zones from different relays overlap, discriminating between the real fault location and the virtual one is difficult, and malfunction can occur. In this case, the zone length or time delay is usually modified to separate the overlapped zones. However, these changes affect the coordination of the power protection system.**

A clear example of this involves transformer backup protection. Generally, when Zone 2 of a transformer backup protection relay overlaps Zone 2 of an adjacent line backup protection, the method of modifying this zone may not be obvious. To overcome this problem, this paper describes an improved operating scheme using an IEC61850-based distance relay for transformer backup protection.

***Index Terms*—IEC61850, Distance relay, Transformer backup protection, GOOSE message, Quadrilateral relay**

I. Introduction

A differential relay scheme is generally the primary method of transformer protection, and an overcurrent relay or a distance relay scheme is used as a backup. As a general rule in Korea, a distance relay scheme is the method used for backup protection of transformers. Table I shows the protection rules for transformer backup protection [1].

TABLE I
BACKUP PROTECTION SCHEMES FOR TRANSFORMERS IN KOREA

Voltage Level	Backup Protection Schemes	Backup Zone
765 / 345 kV	Phase Distance Relay	Zone 2 Zone 3
	Ground Distance Relay	Zone 2 Zone 3
345 / 154 kV	Phase Distance Relay	Zone 2

A phase distance relay and ground distance relay use almost the same algorithm and parameter settings. The only difference is in the compensation portion depending on the fault types. Both distance relays encounter a major problem if the same backup zones from different relays overlap. Any fault occurring in the overlapped zone causes a malfunction between the relays. The backup zones are set not to overlap in the conventional step distance relay scheme. In some specific systems, however, the zones must overlap even though the systems conform to the zone setting rule.

These problems are generally handled by changing the time delay or zone size, although this can affect the coordination of the power protection system. Modifying the zone leaves an unprotected area at the end of each zone, and changing the time delay leads to coordination problems with the other side of the relay.

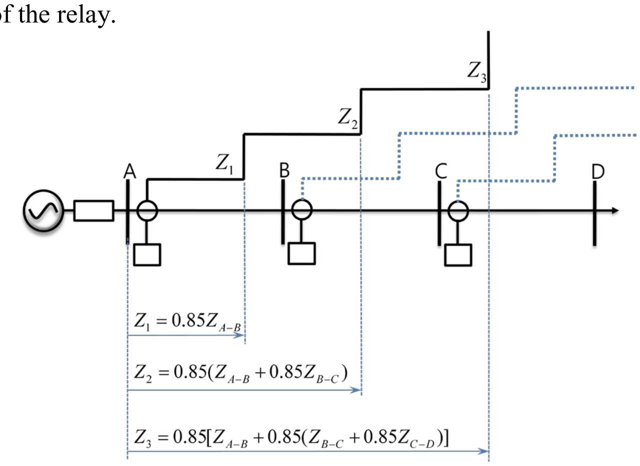

Fig. 1. Grading chart of a radial transmission line

The distance to the neighboring zone is multiplied by a grading factor (GF) to achieve the zone setting as explained by Ziegler [2]. The GF expresses the security margin in relation to the impedance setting. The GF is used in each zone as shown in Fig. 1. This factor takes into account the measuring errors, the instrument transformer errors, and the inaccuracies of the line data. Therefore, a GF of 0.85 is used to achieve a grading margin of 15%.

Under normal circumstances, a GF of 0.85 causes no problem. In Fig. 1, however, if a value of 0.85 is used for each zone when Z_{A-B} is more than five times greater than Z_{B-C}, the primary zone cannot be protected completely as explained in Appendix A. Therefore, another zone setting rule Is required.

Since the purpose of the Zone 2 setting is the complete protection of the primary zone, Zone 2 must cover Z_{A-B}, even if it includes several errors. The zone setting rules are defined in Table II [3].

Although Table II shows the setting rule for transmission line protection, the transformer protection uses the same rule except for the operation time. Even though this rule is applied to each zone, zones can overlap when the impedance of the

This work was supported by the ERC program of MOST/KOSEF (Next-generation Power Technology Center) and the 2nd Brain Korea 21 Project.

Hyung-Kyu Kim, Sang-Hee Kang, Soon-Ryul Nam and Sea-Seung Oh are with the Next-generation Power Technology Center (NPTC) and the Department of Electrical Engineering, Myongji University, Korea. (e-mail : shkang@mju.ac.kr)

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primary zone is much higher than the impedance of the secondary zone.

TABLE II
ZONE SETTING RULE OF THE DISTANCE RELAY SCHEME IN KOREA

	Operation Time	*Setting Rule*
Zone 1	154,345 kV : 1~3 cycles	Phase to phase fault : 85% of the primary zone Phase to ground fault : 75% of the primary zone
	765 kV : 9 cycles	
Zone 2	154 kV : 20 cycles	A. 125% of the primary zone B. 100% of the primary zone + 50% of the secondary zone the larger of A or B.
	345,765 kV : 24 cycles	
Zone 3	100 cycles	A. 100% of the primary zone + 125% of the longest secondary zone B. Permissible load impedance. the larger of A or B.

Transformers are designed to have sufficient impedance for reasons related to system stability. As shown in Fig. 2, Relay 1 is the backup relay for the transformer and Relay 2 is the backup relay for the transmission line. Hence, Zone 2 of Relay 1 can easily overlap Zone 2 of Relay 2 and will be the source of major malfunction of the distance relays when any fault occurs in the overlapped Zone 2.

This paper proposes an improved scheme to cope with the preceding problems without any modification of the zone or time delay. The performance of the proposed scheme has been evaluated for a-phase to ground (a-g) faults on a 765-kV overhead transmission line in the overlapped zone of the system shown in Fig. 2. The fault current signals were generated by a real-time digital simulator (RTDS).

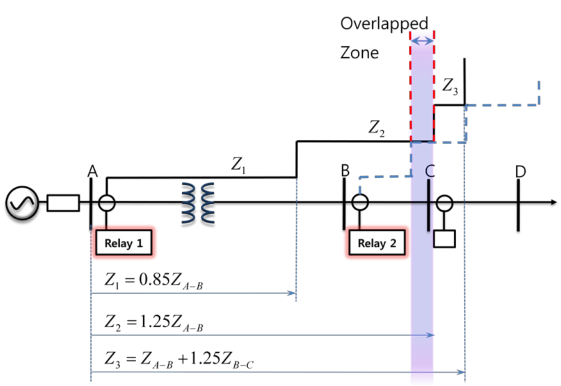


Fig. 2. Grading chart of a radial transmission including the overlapped Zone 2

II. PROPOSED OPERATION SCHEME

A. *GOOSE Message*

According to the IEC61850 standard [4,5], two models are based on peer-to-peer communication: a generic object-oriented substation event (GOOSE) and sampled value (SV). The GOOSE model is a very flexible high-priority reliable mechanism for the fast transmission of substation events such as trips commands, alarms, and indications. GOOSE messages are used to replace the hardwired control signal exchange between intelligent electronic devices (IEDs) for interlocking, protection purposes, and sensitive missions that are time-critical and require high reliability. The information exchange is based on a publisher/subscriber mechanism. The publisher writes the values in a local buffer on the sending side and the receiver reads the values from a local buffer on the receiving side. The communication system is responsible for updating the local buffers of the subscribers. The GOOSE message is multicast and received by the IEDs that have been configured to subscribe to it.

The GOOSE messages contain information that allows the receiving device to know that the status has changed and the time in which this change occurred. The time of the last status change allows a receiving device to set local timers related to a given event. The IEDs receiving the message use the information in the message to determine the appropriate protection response for the given state. The appropriate reaction to GOOSE messages is required when a message timeout due to a communication failure is detected by the IEDs receiving the GOOSE message.

Since the GOOSE message is based on the IEC61850 standard, this message can only be used in automated substations based on IEC61850. Moreover, the devices for communicating the GOOSE message must be installed in the same substation because communicating via GOOSE messages between the IEDs installed in different substations is impossible.

B. *Improved Distance Relaying Scheme*

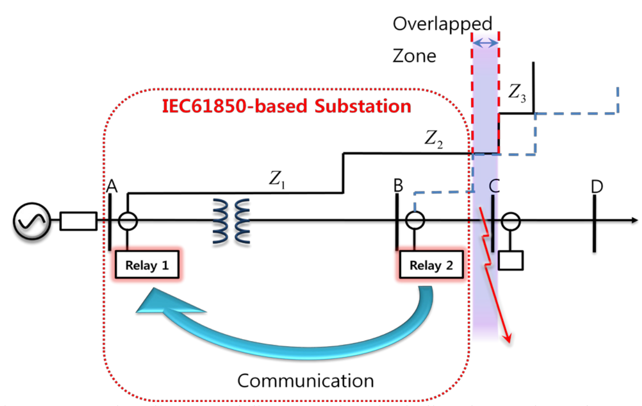


Fig. 3. Operation diagram of distance relays including the overlapped Zone 2

The operation time of Zone 2 is 24 cycles for transformer backup protection. If any kind of fault occurs in the overlapped zone, both relays in the overlapped zone will operate after the same 24 cycles.

In the configuration shown in Fig. 3, if the fault occurs in the overlapped Zone 2, only Relay 2 should operate, while Relay 1 must be blocked. Using communication between Relays 1 and 2 is possible. If the substation is based on an IEC61850 standard, a blocking message can be transmitted via a GOOSE message that must be completed in 24 cycles (400 ms). The communication via a GOOSE message is possible because the IED for transformer backup protection and the IED for the transmission line backup protection are in the same substation.

According to Cho et al. [3], important fast messages such as trip messages, can be transmitted in less than 10 ms in an IEC61850-based substation system using GOOSE messages. Since blocking messages must be completed in less than 24 cycles (400 ms), this concept of using GOOSE messages is feasible.

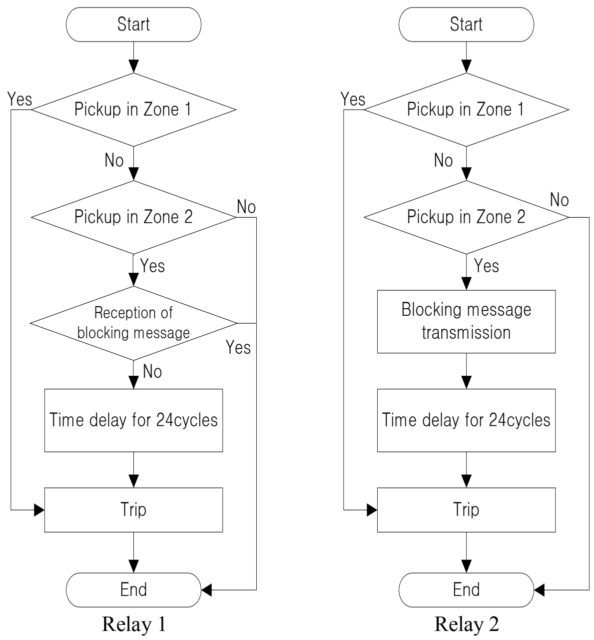


Fig. 4. Flowchart of each relay in the proposed scheme

As shown in Fig. 4, a different algorithm is required in each relay. If any fault occurs in the overlapped Zone 2, Relay 2 has priority over Relay 1. Thus, Relay 1 must be blocked when the fault occurs in the overlapped Zone 2.

Relay 2 sends a blocking message to Relay 1 in a GOOSE message when Relay 2 picks up in Zone 2. Relay 1 must not operate when it receives the blocking message from Relay 2, even though Relay 1 also picks up in Zone 2.

This proposed scheme can solve the coordination problem without any modification of the relay setting rule when the zone is overlapped.

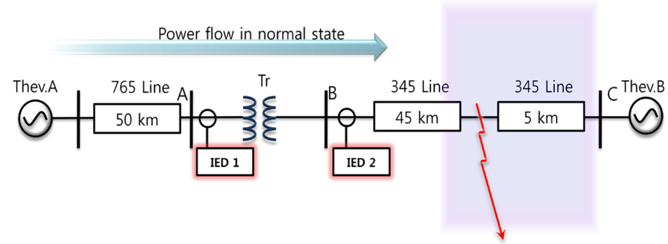
III. Simulations

A. System Configuration

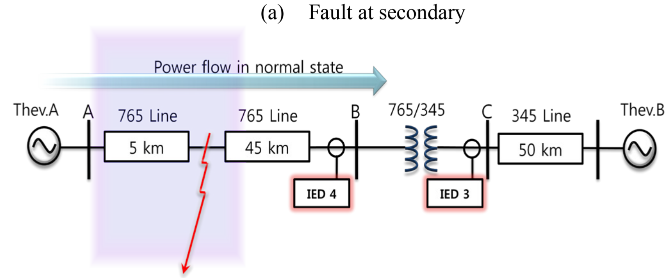
Two transmission systems including transformers were designed as shown in Fig. 5 to test the proposed scheme.

Table III shows the data used in this system. These data are defined for the same case as in Fig. 3 and they are typical of those used by the Korea Electric Power Corporation. The fault resistance and saturation characteristics of the transformer are not considered in this simulation.

Thev.A and Thev.B is the Thevnin equivalent source model.



(a) Fault at secondary



(b) Fault at primary

Fig. 5. Transmission systems included transformer

TABLE III
DATA USED FOR SIMULATION

	Thev.A	*Thev.B*
Voltage	765 kV	345 kV
Frequency	60 Hz	
Angle	0 °	-5 °
	Transformer	
Type	Yg-Yg	
MVA	333 MW	
Voltage	Winding Line 1 : 765 kV Winding Line 2 : 345 kV	
Leakage Reactance	0.1767 PU	
	765 Line [Ω /km]	*345 Line* [Ω /km]
R^+	1.113×10^{-2}	2.241×10^{-2}
L^+	1.679×10^{-1}	2.241×10^{-1}
C^+	1.000×10^{16}	1.000×10^{16}
R^0	1.106×10^{-1}	8.230×10^{-1}
L^0	5.222×10^{-1}	1.221×10^{-1}
C^0	1.000×10^{16}	1.000×10^{16}

Zone 2 is commonly overlapped as explained in Appendix B when the impedance difference between two relays is greater than three times that of one relay.

The impedance is estimated from the measured voltage and current. The impedance of the secondary estimated at the transformer primary is affected by the transformer ratio. Although this effect is considered, the preceding problem of overlap is generally due to the relatively high impedance of the transformer.

In this simulation model, the 765:345 transformer ratio is set to 2.22. If the impedance on the secondary side of the transformer is estimated from data measured at the primary side, the impedance estimated will be 4.93 times greater than the actual impedance as explained in Appendix C.

As shown in (B-2) in Appendix B, Zone 2 is usually overlapped when the primary impedance is at least three times larger than the secondary impedance. However, due to the transformer ratio, Zone 2 should be overlapped when the primary impedance is 14.79 times greater than the secondary impedance seen from the perspective of the transformer primary.

In contrast, the transformer ratio is reversed in the simulation model shown in Fig. 5 (b), and Zone 2 can overlap when the secondary impedance is only 0.6 times bigger than the primary impedance.

These two kinds of simulation system were tested using the RTDS.

B. IEC61850 Simulation System

The system consists of three parts: the RTDS for the input signal, the IEDs, and the PC for monitoring as shown in Fig. 6. Each IED is made up of two modules, one for the distance relay and the other for communication. The distance relay module is based on a 32-bit digital signal processor (Texas Instruments), and the communication module is based on an IXP-420 network processor with an embedded Linux 2.6 kernel. Controller-area network (CAN) communication is used between the two modules.

The purpose of the communication module is to access the IEC61850 network and swap variables in the relay program to match the IEC61850 standard. Every communication module is able to publish GOOSE messages, and also to subscribe to them via the IEC61850 network.

MMS-EASE Lite (Sisco) is a C language source code package for the Manufacturing Message Specification (MMS) protocol that is used for the IEC61850 network. It is optimized for use in IEDs.

When the distance relay of IED 2 picks up in its own Zone 2, information concerning this event is transmitted to the communication module via CAN communication, and the communication module sends the blocking message to IED 1 as a GOOSE message. The communication module of IED 1 receives this message, and blocks the trip from Zone 2 of IED 1. The GOOSE control variable for the trip message, *gcbTrip*, is used only for the blocking message, not for the trip.

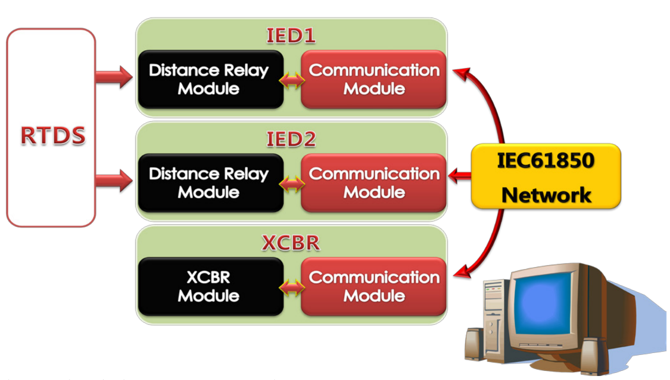


Fig. 6. Simulation system overview

C. Simulation results

The simulation used the generic ground distance relay algorithm based on the discrete Fourier transform; the details are described elsewhere [7]. A quadrilateral-type distance relay was used with the zone settings provided by Xelpower [8]. The operational priority between IEDs was configured in the algorithm and could be easily changed.

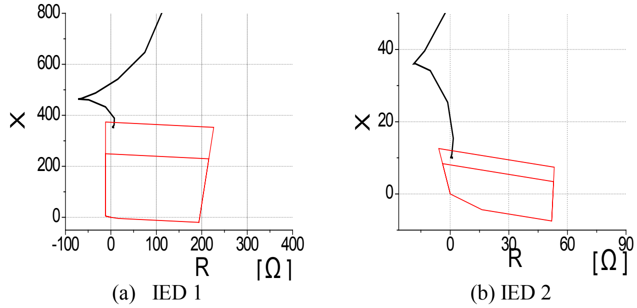


Fig. 7. Impedance trajectories of each relay for the configuration shown in Fig. 5(a)

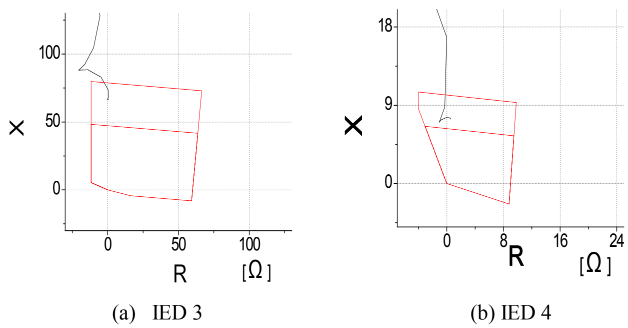


Fig. 8. Impedance trajectories of each relay for the configuration shown in Fig. 5(b)

Figure 7 shows the impedance trajectory of both relays when the a-g fault occurs in the overlapped zone. Figure 7(a) is for IED 1, the distance relay for transformer backup protection, and 7(b) is for IED 2, the distance relay for transmission line backup protection. The measuring points of each relay are shown in Fig. 5. Figure 7 shows that both relays in Zone 2 pick up, even though the fault occurs on 90% of the transmission line. In this case, both relays will trip after the 24-cycle delay.

Figure 8 shows the results for the configuration of Fig. 5(b). Again, both relays pick up, causing the same problem as in Fig. 7.

In these cases, the communication module of each IED that has priority publishes the blocking message via a GOOSE message. Figure 9 shows a snapshot of the network activity captured using Ethereal, a message analyzer.

The secondary IED receives this blocking message and the trip is blocked, as shown in Fig. 10.

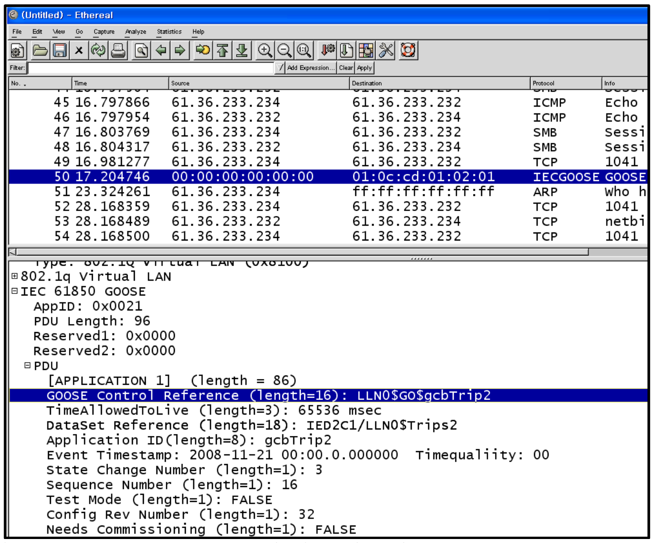


Fig. 9. GOOSE message captured using Ethereal

Figure 10 shows that the communication time for the blocking message is 70 ms. Since the blocking message must be transmitted within 24 cycles (400 ms), this performance is adequate.

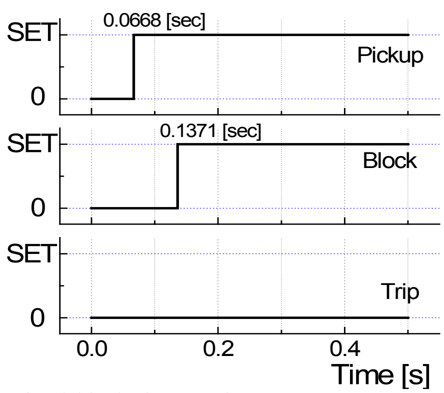


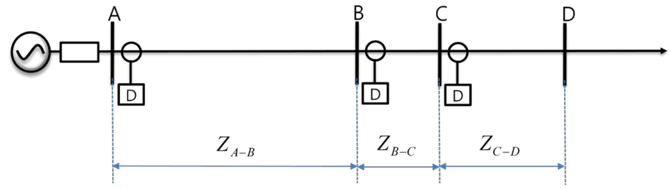
Fig. 10. Signals of variables in the secondary IED

IV. Conclusion

An improved operating scheme using an IEC61850-based distance relay for transformer backup protection was proposed. The main concepts were proved using software and hardware simulation with data from the Korean power system. RTDS was used for hardware simulation to generate the input signals. Sisco's MMS-EASE Lite was used to create the IEC61850 network.

This paper has shown that the proposed scheme eliminates the malfunction of the distance relay when a fault occurs in the overlapped zone behind the transformer. The proposed scheme is thus capable of dealing with zone overlapping problems behind the transformer.

V. Appendixes



A. If the GF is set to 0.85, the impedances of Zones 1 and 2 can be expressed as

$$Zone\ 1 = 0.85\, Z_{A-B}$$
$$Zone\ 2 = 0.85(Z_{A-B} + 0.85 Z_{B-C}) \quad \text{(A-1)}$$

Since Z_{A-B} must be covered by Zone 2, Zone 2 must be modified if it is not large enough to protect Z_{A-B} completely.

$$0.85(Z_{A-B} + 0.85 Z_{B-C}) < Z_{A-B}$$

$$0.7225\, Z_{B-C} < 0.15\, Z_{A-B}$$

$$4.817 < \frac{Z_{A-B}}{Z_{B-C}} \quad \text{(A-2)}$$

Because of (A-2), the zone setting using a GF of 0.85 must not be used if Z_{A-B} is more than 4.817 times larger than Z_{B-C}.

B. According to the rule in Table II, the dimensions of Zones 1 and 2 are defined as follows at each relay point.

$$Zone\ 1\ of\ A = 0.75 Z_{A-B}$$
$$Zone2\ of\ A = 1.25 Z_{A-B}$$
$$Zone\ 1\ of\ B = 0.75 Z_{B-C}$$
$$Zone\ 2\ of\ B = 1.25 Z_{B-C}$$

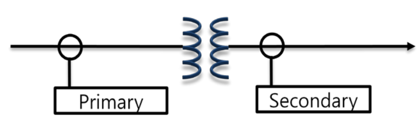
Zone 2 of A must exceed *Zone 1* of B to overlap.

$$1.25 Z_{A-B} > 0.75 Z_{B-C} + Z_{A-B} \quad \text{(B-1)}$$

$$Z_{A-B} > 3 Z_{B-C} \quad \text{(B-2)}$$

As a result, the Zone 2s of both relays overlap when the primary impedance is three times larger than the secondary impedance.

C. In a system that includes a transformer, the transformer ratio must be considered when estimating the impedance.



The impedance is estimated with the voltage and current at the measuring point. Therefore, if the impedance of the secondary is estimated with voltage and current measured at the primary, the data are affected by transformer ratio,

$$Z_{S\_P} = \frac{\alpha V_S}{\frac{1}{\alpha} I_S} = \alpha^2 \frac{V_S}{I_S} \quad \text{(C-1)}$$

where α is the transformer ratio, Z_{S_P} is the secondary impedance estimated at the primary point, and V_S and I_S are the actual value of the voltage and current, respectively, at the secondary. Hence, if the impedance is estimated at the other side of the transformer, the squared transformer ratio alters the estimate.

VI. References

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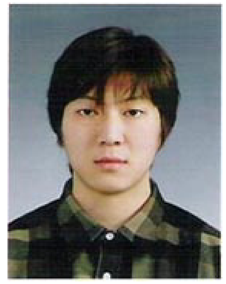
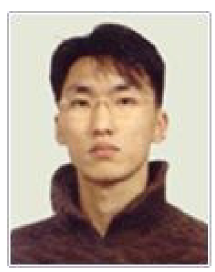
VII. Biographies



Hyung-Kyu Kim received his B.S. degrees from Myongji University, Korea in 2008. He is now studying for his M.S. degree at Myongji University and has been with the Next-generation Power Technology Center in Korea since 2008. His main research interest is power system protection.

Sang-Hee Kang is a professor at Myongji University, Korea. He received the B.S., M.S. and Ph.D. degrees from Seoul National University, Korea in 1985, 1987 and 1993, respectively. He was a visiting fellow and a visiting scholar at the University of Bath, United Kingdom in 1991 and 1999, and he has been with Next-generation Power Technology Center, Korea since 2001. He was an honorary academic visitor at the University of Manchester, UK in 2007. His main research interest is the development of digital protection systems for power systems using digital signal processing techniques.

Soon-Ryul Nam is an assistant professor at Myongji University. He received the B.S., M.S. and Ph.D. degrees from Seoul National University, Korea in 1996, 1998 and 2002, respectively. Currently, he was an assistant professor at Chonnam National University, Gwangju, Korea. He is also with Next-generation Power Technology Center (NPTC), Korea. His main research interest is the development of digital protection systems for power systems.



Sea-Seung Oh received his B.E. and M. E. degrees from Korea University, South Korea. He received the Ph. D. degree from Korea University, Korea, in 2007. He was a Post-Doctoral at Seoul National University, Korea for one year. He is currently a research professor in BK21 division of Department of Electrical Engineering of Myongji University, Korea. His research interests include computer applications in power system analysis, operation, controls and visualization.