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A Study on the Agent (Protective Device)-based Fault Determination and Separation Methodology for Smart Grid Distribution System

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Abstract – This paper proposes a new fault isolation methodology for a smart protective device which plays an agent role on the smart grid distribution system with the distributed generation. It, by itself, determines accurately whether its protection zone is fault or not, identifies the fault zone and separates the fault zone through the exchange of fault information such as the current information and the voltage information with other protective devices using bi-directional communication capabilities on the smart grid distribution system. The heuristic rules are obtained from the structure and electrical characteristics determined according to the location of the fault and DG (Distributed Generation) when faults such as single-phase ground fault, phase-to-phase short fault and three-phase short fault occur on the smart grid distribution system with DG.

Keywords: Distribution system, Smart grid, Smart protective device, Distributed generation

1. Introduction

Recently, from the perspective of global warming, a smart grid distribution system is receiving great interest which has the distributed power sources and the bi-communication capability between distribution facilities that are required to enhance the rate of green energy generation and improve the efficiency of the energy use. The existing central-based distribution automation systems have significant contribution in improving the power supply reliability for distribution system with radial structure [1-2]. However, because it monitors system status, collects operation data and executes fault processing procedure when any fault occur, based on polling method under one-way communication, it can not be applied directly to a smart grid distribution system with bi-directional communication capability due to the reasons described below. i) Because of a time delay caused by the overloaded server computer and communication traffic to perform the complicated and diversity functions of the smart grid distribution system, power supply reliability may be considerably deteriorated. ii) Because its feeder automation solutions and protective devices were developed properly to distribution system with radial structure, it can not be applied directly to a smart grid distribution system which is a mixed of the tree feeders and loop feeders caused by distributed power generations.

Until now, the various methodologies have been presented to support distribution automation system. References [3-4], under normal condition, propose feeder reconfiguration methodologies to reduce the feeder loss of the distribution system, and references [5-6] to obtain the load balancing. On the other hand, references [7-8], under emergency condition, present methodologies to identify fault location, references [9-11] to obtain service restoration and references [12-14] to determine high impedance fault. However, most of these studies propose feeder reconfiguration strategies for central-based distribution automation system based on one-way communication. Although references [15-17] present methodologies using bi-direction communication and in particular, in order to solve the problem i), reference [17] propose heuristic rule-based self-fault zone isolation methodology and self-high impedance fault zone isolation methodology using bi-directional communication separately, because these studies handle only distribution system with radial structure, the proposed methodologies can not be applied directly to smart grid distribution system with a mixed structure of the tree structure and loop structure. Thus, in order to enhance the smart grid distribution system's operating efficiency and reliability, a smart protective device is needed which can overcome the problems i) and ii) by identifying and isolating by itself the fault using its bi-direction communication capability when any fault occurs on the smart grid distribution system with a mixed structure of the tree structure and loop structure caused by distributed generations.

Accordingly, this paper proposes a new fault isolation methodology for the smart grid distribution system with the distributed distribution. It, by itself, determines accurately whether its protection zone is fault or not, identifies the fault zone and separates the fault zone through the exchange of fault information such as the current information, the voltage information with other protective devices using bi-directional communication capabilities on the smart grid distribution system. The heuristic rules are obtained from the structure and electrical characteristics determined according to the location of the

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fault and DG (Distributed Generation) when faults such as single-phase ground fault, phase-to-phase short fault and three-phase short fault occur on the smart grid distribution system with DG

2. Design of Smart Protective Device

A smart protective device is a heuristic rule-based solution that it, by-itself, can identify and isolate the fault zone by exchanging fault information with adjacent devices through two-way communication capability.

2.1 Heuristic rules

The heuristic rules (HRs) are obtained from the structure and electrical characteristics determined according to the location of the fault and DG when faults such as three-phase short fault, phase-to-phase short fault and single-phase ground fault occur on the smart grid distribution system with DG

HR 1] If any smart protective device experience the fault current, its W_X is equal to W_R and its protection zone is dead end zone, its protection zone is fault zone. This rule can be applied when any fault occurs at downstream position from the DG and at dead end zone.

Here, W_X is the direction of the measured current at self-position of any smart protective device, W_R is the direction of the current I_T flowing from substation transformer of tree-structure feeder without DG. On the other hand, W_T and W_D, as shown in Figs. 1-2, represent the direction of the fault current I_T flowing from substation transformer and the direction of the fault current I_D flowing from distributed generation when a fault occurs at the location f on the feeder with DG separately. And T represents a substation transformer (MTr), D the distributed generation, and bus $B_{i,j}$ the location of jth protective device of ith feeder. And the zone protected by the protective device on $B_{1,5}$ is dead-end zone.

HR 2] If any smart protective device experience the fault current, and all the downstream smart protective devices on its protection zone which is based on the direction of the fault current does not experience the fault current (more precisely, is less than the fault current threshold value, I_{SET}), its protection zone is fault zone.

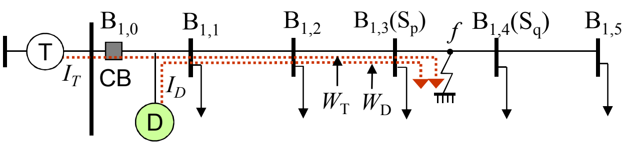

Fig. 1. Case a fault occurs at downstream position of DG

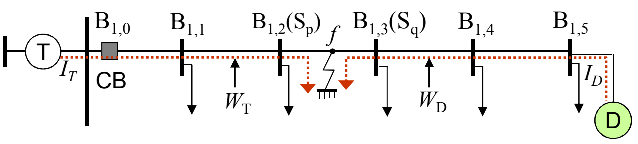

Fig. 2. A case with DG at the end point of the feeder

This rule can be applied when single-line ground fault in which only one-side end of broken conductor is grounded occurs on tree or loop structure feeder. Fig. 1 shows when the fault occurs on tree structure feeder. As shown in Fig. 1, when any fault occurs at downstream position from the DG, i.e., when any fault occurs at the position f on the zone surrounded by the protective devices S_p and S_q, the protective device S_p experiences the fault current.

However, the downstream smart protective device S_q of its protection zone {S_p, S_q} does not experience the fault current. Keep in mind that in the case of a short fault between two phases or a ground fault with ground resister, the current and voltage measured by S_q does not necessarily become zero.

Fig. 2 shows when the fault occurs on loop structure feeder. As shown in Fig. 2, when any fault occurs at downstream position from the DG, i.e., when any fault occurs at the position f on the zone surrounded by the smart protective devices S_p and S_q, one of S_p and S_q can experience the fault current. Accordingly, Each of S_p and S_q must identify whether its protection zone is fault zone or not separately. If up-side end of broken conductor is grounded, the upstream smart protective device S_p of its protection zone {S_p, S_q} does not experience the fault current, On the other hand, if down-side end of broken conductor is grounded, the downstream smart protective device S_q does not experience the fault current.

HR 3] If any smart protective device experience the fault current, anyone of the downstream smart protective devices on its protection zone which is based on the direction of the fault current experience the fault current, its W_X is equal to W_R and W_X of one of downstream protective devices on its protection zone is not equal to W_R, its protection zone is fault zone.

This rule can be applied when a single-line ground fault with the unbroken conductor, a short fault between two phases or a three phase short fault occurs on loop structure feeder. When any fault occurs at upstream position from the DG, i.e., when any fault occurs at the position f on the zone surrounded by the protective devices S_p and S_q as shown in Fig. 2, both of S_p and S_q experience fault current. At this time, if two protective devices all try to identify whether their protections are fault zone or not, it is not efficient. In this case, a smart protective deice S_p in which its W_X is equal to W_R will be enough for fault zone identification to continue with the fault zone search process. Here, the direction of current measured by the smart protective device S_p is W_R, but the direction of current measured by the downstream smart protective device S_q of its protection zone is reverse to W_R.

Fig. 3 shows a distribution system introduced to explain the direction of fault current when a single-line ground fault with the unbroken conductor occurs on loop structure feeder.

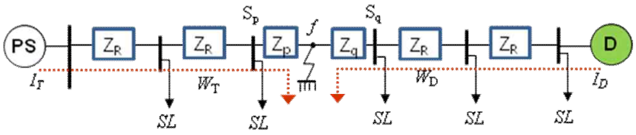

Fig. 3. Example system to show direction of fault current

In order to simply notation, and show clearly the changes of the voltage and current before and after the fault at the positions of smart protective devices S_p and S_q, the single phase circuit was adopted, and all impedances and section loads on the circuit loads were represented as the resistance component values. In Fig. 3, the voltage, the frequency and the source impedance of power source (PS) are 13.2 kV, 60Hz and 3Ω separately, and the voltage and internal impedance of the distributed generation (D) is 13.2 kV and 20Ω. Section impedance Z_R is 0.5Ω, Z_p 0.25Ω, Z_q 0.25Ω, the ground resistance 1Ω, and section load (SL) 100Ω.

The simulation results obtained from EMTP/ATPDraw shows in Fig 4. In Fig. 4, the fault triggering time is 33.3 [ms], and the fault clearing time is 116.7[ms]. Before the fault, the voltage values at S_p and S_q are almost the same, and phase differences between voltage and current at S_p and S_q are zero. On the other hand, after the fault, the voltage values at S_p and S_q decrease greatly, and the current phase at S_q show the difference of 180 degree as compared with that at S_p. it means that the direction of current after the fault at S_q is reverse direction as compared with that at S_p.

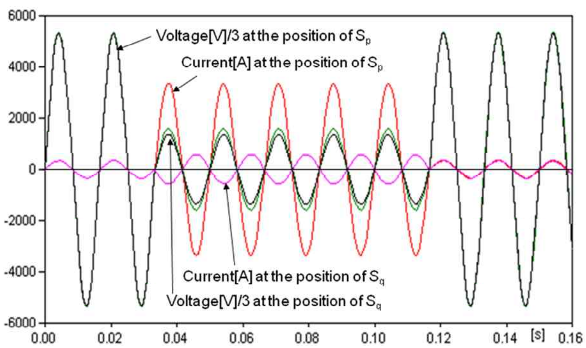

Fig. 4. The voltage and current before and after the fault

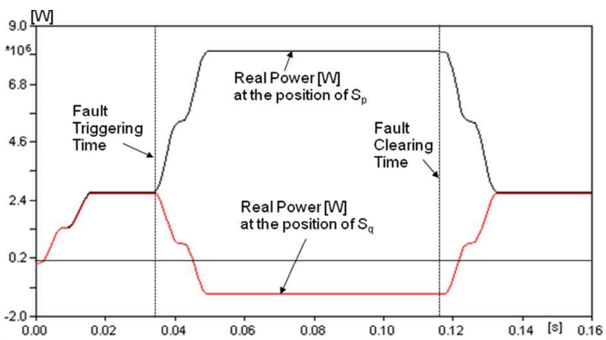

Fig. 5. The real power before and after the fault

Fig. 5 shows the change of the real power before and after the fault at S_p and S_q. The real power before and after the fault at S_p is great than zero (Positive), it means the current direction before and after the fault is the same. On the other hand, the real power after the fault at S_q is less than zero (Negative), it means the current direction before the fault is reverse as compared with that before fault.

2.2 The modeling for Two-way communication

The proposed smart protective device identifies and isolates the fault zone before it is opened as lock-out status based on the heuristic rules HR 1-3 abovementioned after exchanging the fault information such fault current value, current direction with adjacent protective devices on the feeder. To apply the proposed method to smart grid distribution system, it is needed for any smart protective device to identify the electrical connectivity with other smart protective devices on the feeder. Therefore, a source zone and a sink zone for each smart protective device are defined which is enclosed by protective devices and based on the current direction W_R [17].

Fig. 6 shows the source zone and sink zone of the distribution system.

For example, a smart protective device S_5 has the zone {S_2, S_3, S_4, S_5} as source zone and the zone {S_5, S_6} as sink zone. Here, the upstream smart protective device set (USPDS) is {S_2, S_3, S_4} and the downstream smart protective device set (DSPDS) {S_6}, and the sink zone becomes the protection zone. Also, a smart protective device S_4 has zone {S_2, S_3, S_4, S_5} as source zone, the zone {S_4, S_7, S_8} sink zone and DSPDS {S_7, S_8}.

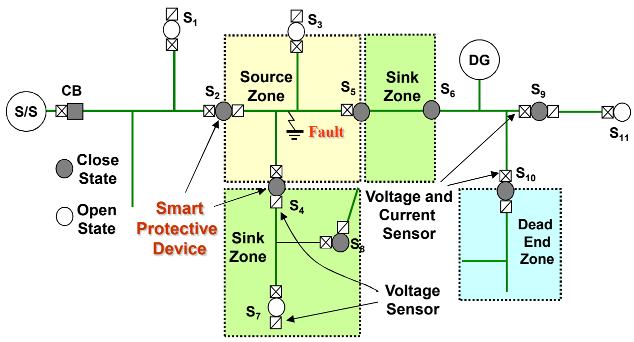

Fig. 6. The zone modeling for two-way communication

2.3 The inference procedure

Fig. 7 shows inference procedure of fault zone of smart protective device. In Fig. 7, I_A, I_B, I_C, I_O, V_A, V_B and V_C represent A-phase current, B-phase current, C-phase current, zero phase current, A-phase voltage, B-phase voltage and C-phase voltage measured at self-position of each protective device.

In Ix, X means fault phase among three phases. I_X^k and W_X^k represent the current value and direction of kth

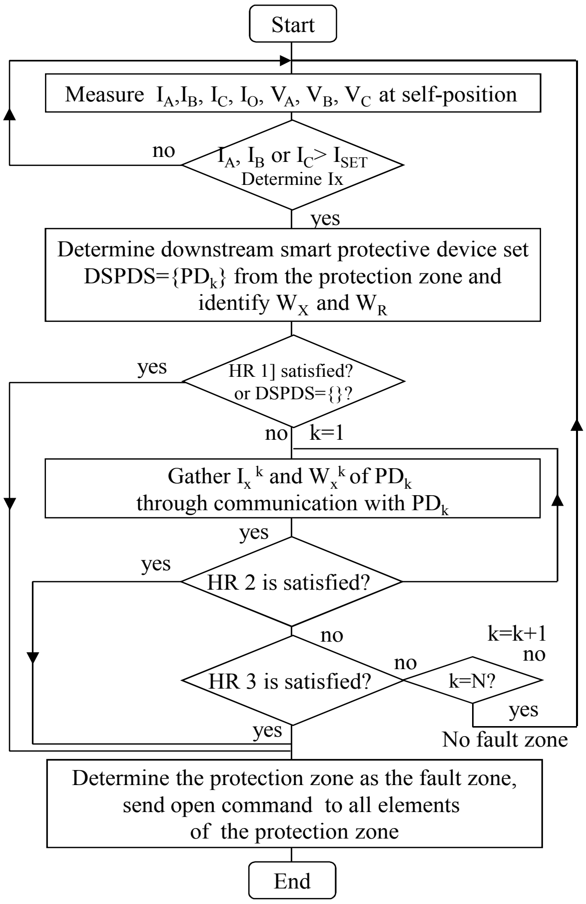

Fig. 7. The inference procedure of fault zone

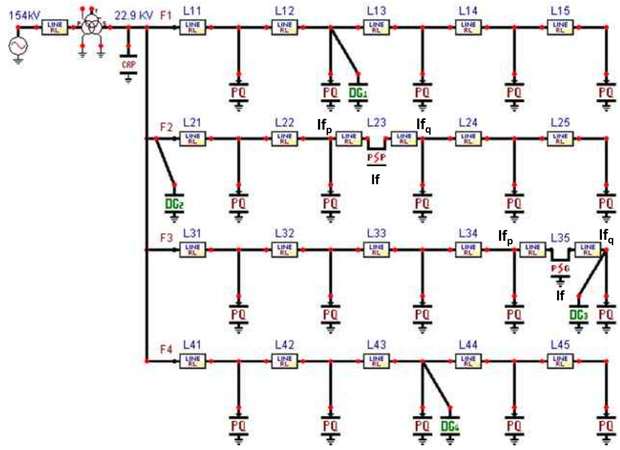

Fig. 8. Test smart grid distribution system

Table 1. Modeling constant

#	Classification	Modeling Object		Modeling Constant
1	Distribution Substation	154kV side	100 MVA based	$Z_1(Z_2)$= 0.131+j1.314 Z_0= 0.361+j1.986
		MTr. (45MVA)		$Z_1(Z_2)$= 35.49 Z_0= j14.87
		$\%Z_{NGR}$		Z_0= j11.441(6Ω)
		Bus side		$Z_1(Z_2)$=0.13+j36.80 Z_0= j49.32
		CAP (Capacitor)		13MVA
2	Distribution Feeder	Voltage		22.9kV
		Line type		ACSR 160mm^2
		Line constant		$Z_1(Z_2)$=3.86+j7.42%/km Z_0=9.87+j22.68%/km
		Line section	Number	5
			Length	2km
			RL Load	0.30 MW+j0.26 MVAR
			Capacitor	0.15MVAR
3	DG (Distributed Generation)	D_1 (WT)	100 MVA based	1MVA, $Z_1(Z_0)$=500
		D_2 (WT)		2MVA, $Z_1(Z_0)$=250
		D_3 (WT)		2MVA, $Z_1(Z_0)$=250
		D_4 (WT)		1MVA, $Z_1(Z_0)$=500

element PD_k of downstream smart protective device set (DSPDS). I_{SET} represents threshold value which determines whether the current measured at self-position is fault current or not. And N is the number of downstream smart protective devices of the protection zone.

At first, each smart protective device monitors A-phase, B-phase, C-phase and O-phase current at the self-position. If any phase current of any smart protective device is greater than I_{SET}, the phase is defined as fault phase X and the phase current as fault current I_X, and then DSPDS is determined from its protection zone information shown in Fig. 6, and W_X and W_R for the fault phase are identified. Next, it, when k is 1, obtains the fault information I_X^k and W_X^k though communication with element (PD_k) of DSPDS and identifies the fault zone by driving the heuristics rules HR 1-3 based on the collected fault information.

3. Simulation Results

A smart grid distribution system with 4 feeders is presented to prove the effectiveness of the proposed methodology. Each feeder consists of five line sections and a DG. Fig. 8 shows the configuration of the smart grid distribution system designed using EMTP/ATPDraw.

In Fig. 8, the symbol CAP represents a capacitor installed for reactive power compensation of MTr load, the symbol DG_i ith distributed generation D_i, the symbol PQ the RL load/capacitor of line section, L_{ij} jth line section of ith feeder, the symbol P/P the phase-to-phase short (or three-phase short) fault generator and the symbol P/G the single-phase ground fault generator.

Table 1 shows the modeling constant for test smart grid system shown in Fig. 8. This modeling data is based on the reference [18]. In Table 1, D_i(WT) represents ith distributed generation is wind turbine generator.

To prove the effective of the proposed methodology, total 16 cases shown Table 2 are simulated using EMTP / ATPDraw, In Table 2, # represents the fault case number. FT, k and FS field of Fault Part represent the fault type, the fault feeder number and the fault zone (line section) separately. In particular, in the fault type, ‘1’ means the single-phase ground fault at A-phase, ‘2’ the phase-to-phase short fault between A-phase and B-phase and ‘3’ the

Table 2. Simulation result

#	Fault			Fault Current [A]					IR	
	FT	k	FS	I_{CB}	I_{fp}	I_f	I_{fq}	W_X	k	FZ
1	1	1	$L_{1,1}$	5851	5851	6328	456	Negative	1	$L_{1,1}$
2	2	1	$L_{1,2}$	4313	4278	4702	400	Negative	1	$L_{1,2}$
3	3	1	$L_{1,4}$	2934	3270	3270	0	-	1	$L_{1,4}$
4	1	1	$L_{1,5}$	1626	1838	3252	0	-	1	$L_{1,5}$
5	1	2	$L_{2,1}$	5374	6081	6081	0	-	2	$L_{2,1}$
6	2	2	$L_{2,3}$	2970	3394	3394	35	Positive	2	$L_{2,3}$
7	3	2	$L_{2,4}$	2793	3069	3069	0	-	2	$L_{2,4}$
8	1	2	$L_{2,5}$	1556	1732	1732	0	-	2	$L_{2,5}$
9	1	3	$L_{3,1}$	5798	5798	6470	665	Negative	3	$L_{3,1}$
10	2	3	$L_{3,2}$	4242	4242	4914	693	Negative	3	$L_{3,2}$
11	3	3	$L_{3,3}$	3712	3712	4596	866	Negative	3	$L_{3,3}$
12	1	3	$L_{3,5}$	1838	1803	2722	956	Negative	3	$L_{3,5}$
13	1	4	$L_{4,1}$	5869	5869	6328	440	Negative	4	$L_{4,1}$
14	2	4	$L_{4,2}$	4313	4348	4702	385	Negative	4	$L_{4,2}$
15	3	4	$L_{4,4}$	2988	3412	3412	0	-	4	$L_{4,4}$
16	1	4	$L_{4,5}$	1662	1980	1980	0	-	4	$L_{4,5}$

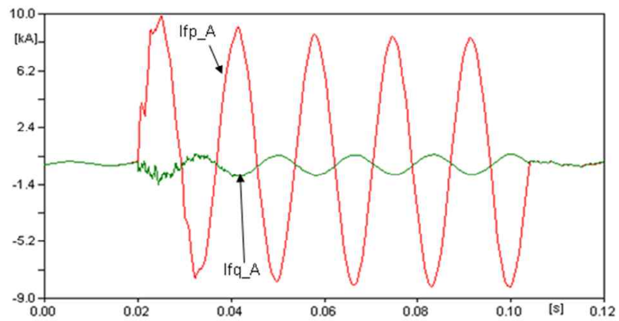

Fig. 9. Simulation result for case 1

three-phase short fault. Also, $L_{k,j}$ means jth zone of kth feeder F_k. In the Fault Current Part, I_T the flowing current from substation transformer current, ID_i the flowing current from D_i, I_{CB} the current at the position of circuit breaker on fault feeder F_k, I_{fp} the incoming current into FS, I_{fq} the outgoing current from FS, I_f the fault current at FS and W_X the current direction of If_q. In particular, all field values of this Fault Current Part are A-phases values except the phase-to-phase short fault cases (case 2, 6, 10 and 14). The phase-to-phase short faults abovementioned are obtained by (A-phase + B-phase)/2. In the IR Part, the filed FZ shows the fault zone obtained by applying the proposed inference procedure to each case.

CASE 1) Single-phase ground fault at the zone $L_{1,1}$

This case simulates a single ground fault occurred at A-phase on the zone $L_{1,1}$ as shown in the case 1 of Table 2. The simulation results of the case 1 show in Table 2. In particular, Fig. 9 shows incoming current Ifp_A into the fault zone and the outgoing current Ifq_A from the fault zone. In this case, because a fault occurred at upstream position from distributed generation, the direction of Ifq_A is reverse direction to Ifp_A, Accordingly, the zone $L_{1,1}$ can be inferred as the fault zone by applying HR 3. This

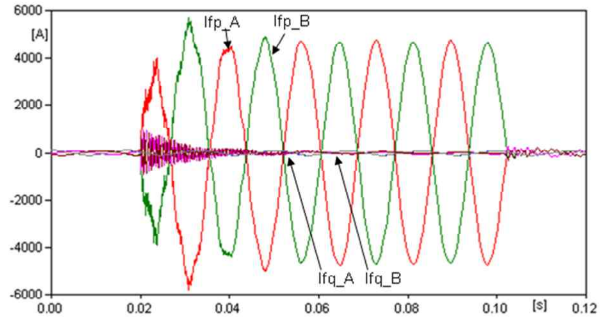

Fig. 10. Simulation result for case 6

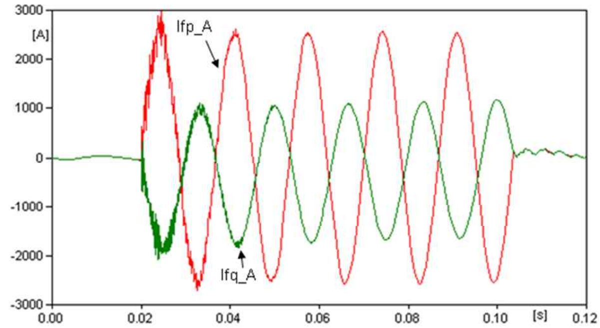

Fig. 11. Simulation result for case 12

inferred fault zone (FZ) is exactly the same as the simulated fault zone (FS).

CASE 6) Phase-to-phase short fault at the zone $L_{2,3}$

This case simulates a phase-to-phase short fault occurred at A-phase and B-phase on the zone $L_{2,3}$ as shown in the case 6 of Table 2 and 3. All simulation results of the case 6 show in Table 2.

Fig. 10 shows the incoming A-phase and B-phase currents Ifp_A and Ifp_B into the fault zone, and the outgoing A-phase and B-phase currents Ifq_A and Ifq_B from the fault zone.

In this case, because a fault occurred at downstream position from distributed generation, Ifq_A is close to zero. Accordingly, the zone $L_{2,3}$ can be inferred as the fault zone by applying HR 2. This inferred fault zone (FZ) is exactly the same as the simulated fault zone (FS). In case of the phase-to-phase short fault, the phase difference between Ifp_A and Ifq_A is exactly 180 degree as shown in Fig. 10.

CASE 12) Single-phase ground fault at $L_{3,5}$

This case simulates a single ground fault occurred at A-phase on the zone $L_{3,5}$ as shown in the case 12 of Table 2. All simulation results show in Table 2.

Fig. 11 shows the incoming A-phase current Ifp_A into fault zone and the outgoing A-phase current Ifq_A from the fault zone. In this case, because a fault occurred at upstream position from distributed generation, Ifq_A is reverse direction to Ifp_A, Accordingly, the zone $L_{3,5}$ can be inferred as the fault zone by applying HR 3. This

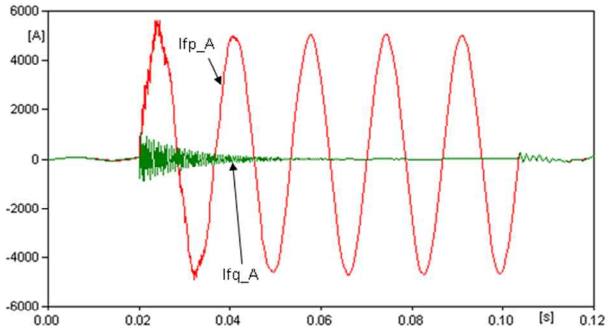

Fig. 12. Simulation result for case 15

inferred fault zone (FZ) is exactly the same as the simulated fault zone (FS).

CASE 15) Three-phase short fault at the zone $L_{4,4}$

This fault case simulates a three-phase short fault occurred on the zone $L_{4,4}$ as shown in case 15 of Table 2. All simulation results shows in Table 2 and 3. In particular, Fig. 12 shows the incoming A-phase current Ifp_A into the fault zone and the outgoing A-phase current Ifq_A from the fault zone. In this case, because a fault occurred at downstream position from distributed generation, Ifq_A is close to zero as shown Fig. 12. Accordingly, the zone $L_{4,4}$ can be inferred as the fault zone by applying HR 2. This inferred fault zone (FZ) is exactly the same as the simulated fault zone (FS).

As explained in the cases 1, 6, 12 and 15, the inference results (IR) for all cases shown in Table 2 is exactly same as the simulated fault zones. Therefore, it can be identified that the proposed methodology is very effective to the smart grid distribution system with distributed generations

4. Conclusions

In this paper, a heuristic based methodology for smart protective device was designed, which, by itself, identifies and isolates a fault zone after exchanging of fault information such as fault information with other protective devices using bi-directional communication capabilities on the smart grid distribution system. The heuristic rules were extracted from the electrical and structural defined specifically according to the arrangement of the fault and DG when the faults of the diverse type occur at the diverse locations on smart grid distribution with DGs. The methodology proposed was proved for typical test model, and its effectiveness was proved by showing the exact inference results of fault zone for the given fault tests.

Acknowledgments

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References

[1] C.H. Castro, J.B. Bunch, and T.M. Topka, “Generalized algorithms for distribution feeder deployment and sectionalizing,” IEEE Trans. on Power Apparatus and Systems, Vol. PAS-99, No. pp. 549-557, March/April 1980.

[2] K. Aoki, K. Nara, M. Itoh, T. Satoh, and H. Kuwabara, “A new algorithm for service restoration in distribution systems,” IEEE 89 VM 085-2 PWRD. 1989.

[3] S. Civanlar, J. J. Grainger, H. Yin, and S. S. H. Lee, “Distribution feeder reconfiguration for loss reduction,” IEEE Transactions on Power Delivery, Vol. 3, No. 3, pp. 1217-1223, July 1988.

[4] M. E. Baran and F. F Wu, “Network reconfig-uration in distribution systems for loss reduction and load balancing,” IEEE Trans. On PWRD, Vol. 4, pp. 1401-1407, 1989

[5] K. Aoki, H. Kuwabara, T. Satoh, and M. Kanezashi, “An efficient algorithm for load balancing of transformers and feeders by switch operation in large scale distribution Systems,” IEEE Trans. on Power Delivery, Vol. 3, No. 4, pp. 1865-1872, Octo-ber 1988.

[6] Y.-Y. Hsu, J.-H. Yi, S.S. Liu, Y. W. Chen, H. C. Feng, and Y. M. Lee, “Transformer and feeder load balancing using a heuristic search approach,” IEEE Trans. on PWRD, Vol. 8, No. 1, pp. 184-190, 1993.

[7] A. A. Girgis , C. M. Fallon, and D. L. Lubkeman, “Fault location technique for rural distribution feeders,” IEEE Trans. on Industry Applications, Vol. 29, No. 6, pp. 1170-1175, November 1993.

[8] R. Das, M. S. Sachdev and T. S Sidhu, “A fault locator for radial subtransmission and distribution lines,” IEEE Power Engineering Society Summer Meeting, Vol. 1, pp. 443-448, 2000.

[9] A. L. Morelato and A. Monticelli, “Heuristic search approach to distribution system restoration,” Elec-tric Power Systems Research, Vol. 4. No. 4, pp. 2235-2241, October 1989.

[10] Yuan-Yih Hsu, H. M. Huang and H. C. Kuo, “Distribution system service restoration using a heuristic search approach,” IEEE Trans. on Power Delivery, Vol. 7, No. 2, pp. 734-740, April 1992.

[11] Qin Zhou, D. Shirmohammadi, and W.-H.E. Liu, “Distribution feeder reconfiguration for service restoration and load balancing,” IEEE Transactions on Power Systems, Volume 12, No. 2, pp. 724-729 May 1997.

[12] B. D. Russel and R. P. Chinchali, “A digital signal processing algorithm for detecting arcing faults on power distribution feeders,” IEEE Trans. on Power Delivery, Vol.4, No.1, Jan. 1989.

[13] T.M. Lai, L.A. Snider, E. Lo, and D. Sutanto, “High

impedance fault detection using discrete wavelet transform and frequency range and RMS conversion," IEEE Trans. on Power Delivery, Vol. 20, No. 1, pp. 397-407, Jan. 2005.

[14] M. Michalik, W. Rebizant, M. Lukowicz, and Seung-Jae Lee, and Sang-Hee Kang, "High-impedance fault detection in distribution networks with use of wavelet-based algorithm," IEEE Trans. on Power Delivery, Vol. 21, No. 4, pp. 1793-1802, Oct. 2006.

[15] A. Apostolov, J. Beatty, et al., "Application of peer-to peer communications for protective relaing," IEEE PSRC Working Group H5 Report to the Communications Subcommittee, 2000.

[16] Communication Networks and Systems in Substations, IEC 61850, 2003, First edition.

[17] Yun-Seok Ko, "A self-isolation method for the HIF zone under the network-based distribution system," IEEE Trans. Power Delivery, Vol. 24, No. 2, pp. 884-891, April 2009.

[18] KEPCO, "A study on the actual examination of bidirectional protection for interconnecting distributed resources with distribution system," KEPRI Technical Report TR. H02. S2009.0998, Feb. 2009.

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