A Group Setting of IED in Microgrid Protection Management System

Jyh-Cherng Gu, Ming-Ta Yang, Chao-Fong Yan, Hsin-Yung Chung, Yung-Ruei Chang, Yih-Der Lee, Chen-Min Chan, Chia-Hao Hsu

***Abstract*—**There are a number of Distributed Generations (DGs) installed in microgrid, which may have diverse path and direction of power flow or fault current. The overcurrent protection scheme for the traditional radial type distribution system will no longer meet the needs of microgrid protection. Integrating the Intelligent Electronic Device (IED) and a Supervisory Control and Data Acquisition (SCADA) with IEC 61850 communication protocol, the paper proposes a Microgrid Protection Management System (MPMS) to protect power system from the fault. In the proposed method, the MPMS performs logic programming of each IED to coordinate their tripping sequence. The GOOSE message defined in IEC 61850 is used as the transmission information medium among IEDs. Moreover, to cope with the difference in fault current of microgrid between grid-connected mode and islanded mode, the proposed MPMS applies the group setting feature of IED to protect system and robust adaptability. Once the microgrid topology varies, the MPMS will recalculate the fault current and update the group setting of IED. Provided there is a fault, IEDs will isolate the fault at once. Finally, the Matlab/Simulink and Elipse Power Studio software are used to simulate and demonstrate the feasibility of the proposed method.

***Keywords*—**IEC 61850, IED, Group Setting, Microgrid.

I. Introduction

WITH rapid advances in technology and rising demand for electricity, energy depletion and global warming effects are deteriorating. Finding renewable energy resources and developing distributed generation (DG) technology to satisfy the world's growing demand are the worldwide trend. Renewable energy resources, such as solar, wind, hydropower, and biomass energy, offer clean alternatives to fossil fuels that contribute to global warming. DG is composed of renewable energy resources, microturbine and cogeneration. It is a small-scale version of local power system providing an independent operation. A microgrid integrates DGs to provide reliable electricity, friendly environment, and economical power. The microgrid can operate either in grid-connected or islanded mode. In the grid-connected mode, the microgrid is connected to utility. However, once a fault is in utility, the microgrid will be disconnected from utility and connected to DGs to supply continuous power to loads. Such the operation mode is called islanding.

A few attempts have been done on the fault protection of microgrid. Directional overcurrent relay [1] is used to detect overcurrent ground and program the curve of protection coordination. It is hardly to implement the protection because of fault current differ greatly from grid-connected mode and islanded mode in that respect. Distance relay [2] is designed to measure the line impedance between the relay and a selected reach point, and operate only for faults occurring. However, microgrid is a short-range transmission system that is easy to make the relay malfunction. The differential relay [3] checks for current balance between two sides of a transmission circuit or equipment, and it will operate when the difference current exceeds a predetermined value. In current differential scheme, there are two sets of differential relay to robust system reliability. It causes the protection manner higher cost. Under-voltage relay [4] protects load against voltage drop that can lead to power failure; nevertheless, the relay will have a nuisance tripping if the power line suffers a slight disturbance. In addition, a current limiter [5] is suggested to install in microgrid. Whatever modes the microgrid operates, the fault current is limited to a predetermined level. Design the impedance of the limiter is a tough question. It is generally known that the protection strategy of the conventional power system is incapable of microgrid. Using the Intelligent Electronic Device (IED) and a Supervisory Control And Data Acquisition (SCADA) with IEC 61850 communication protocol, the paper proposes a Microgrid Protection Management system (MPMS) to coordinate each IED and clear faults. The work provides the microgrid with a comprehensive protection when the system suffers failure.

J.-C. Gu, C.-F. Yan and H.-Y. Chung are with the Department of Electrical Engineering, National Taiwan University of Science and Technology (NTUST) (e-mail: jcgu@ee.ntust.edu.tw, m10207110@mail.ntust.edu.tw, m10307101@mail.ntust.edu.tw).

M.-T. Yang is with the Department of Electrical Engineering, St. John's University, 499, Sec. 4, Tam King Road, Tamsui District, New Taipei City, Taiwan (corresponding author, phone: 886-2-28013131 ext 6528; fax: 886-2-28013973; e-mail: mtyang@mail.sju.edu.tw).

Y.-R. Chang is with the Institute of Nuclear Energy Research (INER) (e-mail: raymond@iner.gov.tw).

Y.-D. Lee, C.-M. Chan and C.-H. Hsu are with the INER (e-mail: ydlee@iner.gov.tw, chancm@iner.gov.tw, edwardhsu@iner.gov.tw).

II. Protection Scheme of Microgrid Systems

Fig. 1 illustrates the protection scheme of microgrid. The field-testing parameters, including voltage, current, power, and power factor, are measured by IED and transmitted to switch unit and SCADA platform that is built in Elipse Power Studio and SQL servers through Ethernet. Furthermore, the GPS antenna receives the satellite signals and makes the IEDs synchronization by the Network Time Protocol (NTP) server.

A. Logic Programming of IED

The inverse-time characteristic curve is used to perform protection coordination programming in conventional protection. The work proposes the IED logic programming instead of inverse-time characteristic curve. Based on the IEC 61850 GOOSE messages [6], [7], all the messages of fault current can be transmitted among IEDs. A fault will be quickly isolated by means of the algorithms of IED logic programming. Fig. 2 shows an example system with five IEDs, where the magnetic contactor (MC) in IED 5 is normal open and the forward current and reverse current are defined in each IED. The fault protection includes line protection, bus protection and back-up protection. The logic programming configuration of IED 2 (a heavy shade of Fig. 2) is illustrated in Fig. 3.

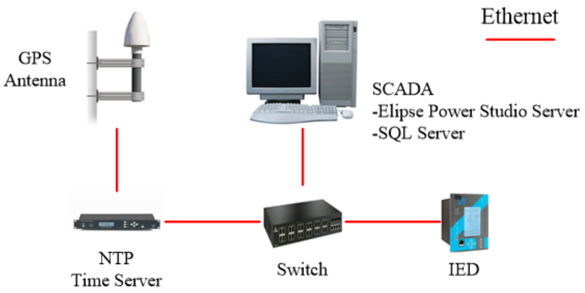

Fig. 1 Microgrid protection scheme

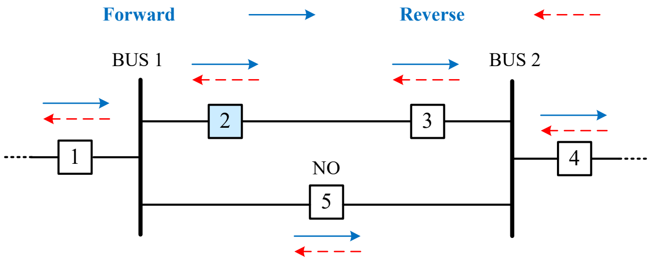

Fig. 2 Illustration of an example system

1. Line Protection

Consider the case where a fault is in the line between IED 2 and IED 3, referring to Fig. 2, IED 2 and IED 3 detect a forward and reverse fault current signals, respectively. As seen in the line protection function block of Fig. 3, IED 2 F_Fault=1 and IED 3 F_Fault=0. IED 2 will issue a tripping signal to MC 2 and send a tripping GOOSE message to IED 3 after 40 ms that is the message transmission delay of GOOSE. The fault is thus isolated by MC 2. Such the protection mechanism is also applicable to IED 3. IED 3 issues a tripping signal to MC 3 and isolates the fault.

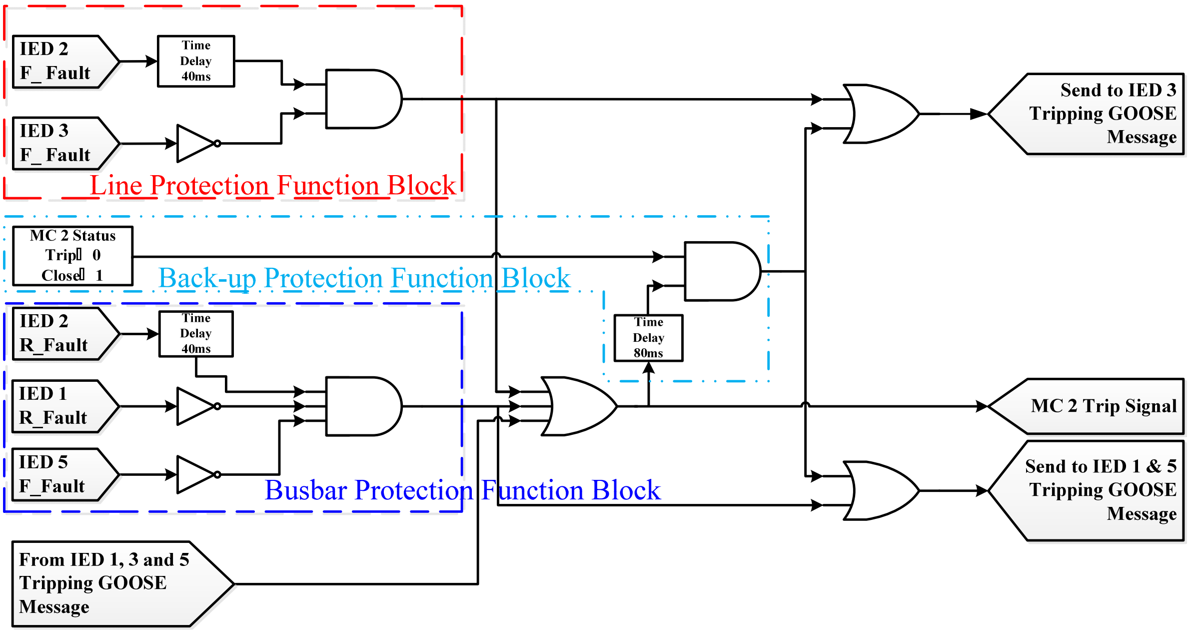

Fig. 3 Logic programming configuration of IED 2

2. Bus Protection

Consider the case where a fault is in BUS 1, IED 1 and IED 2 detect a forward and reverse fault current signals, respectively. As seen in the bus protection function block of Fig. 3, IED 2 R_Fault=1, IED 1 R_Fault=0, and IED 5 F_Fault=0. IED 2 will issue a tripping signal to MC 2 and send the tripping GOOSE messages to IEDs 1 and 5 after 40 ms. The fault is then isolated by MCs 1, 2, and 5.

3. Back-Up Protection

Consider the case where a fault is in the protection zone of IED 2, and the MC 2 does not normally trip in 80 ms. IED 2 will send the tripping GOOSE messages to IEDs 1 and 3 to isolate the fault and accomplish the back-up protection.

B. Group Setting of IED

The work used the IED Arcteq AQ-F215 with eight group settings (labeled as SG 1 to SG 8) as shown in Fig. 4. The Logical Input (LI) terminal is used to control the switch in group setting. Once the microgrid is subjected to change for the variation of microgrid topology, the proposed MPMS evaluates all the values of forward and reverse current in IEDs and decides if the group setting needs to be switched. The current value is evaluated by (1) [8].

$$I_{relay} = \left(I_{faultGRID} \times Mode\right) + \sum_{i=1}^{n}\left(k_i \times I_{faultDG_i} \times S_{DG_i}\right) \quad (1)$$

where, $I_{faultGRID}$: the fault current supplied by utility, *Mode*: the microgrid operation mode, 1: grid-connected, 2: islanded, *n:* the total numbers of the DGs, k_i: the impact factor of DG_i between 0 and 1, $I_{faultDGi}$: the fault current supplied by DG_i, S_{DGi}: the DG_i working mode, 0: ON, 1: OFF.

To switch the group setting, the MPMS is expected to send a command signal to LI terminal via IEC 61850. The group setting of IEDs is performed by SCADA platform.

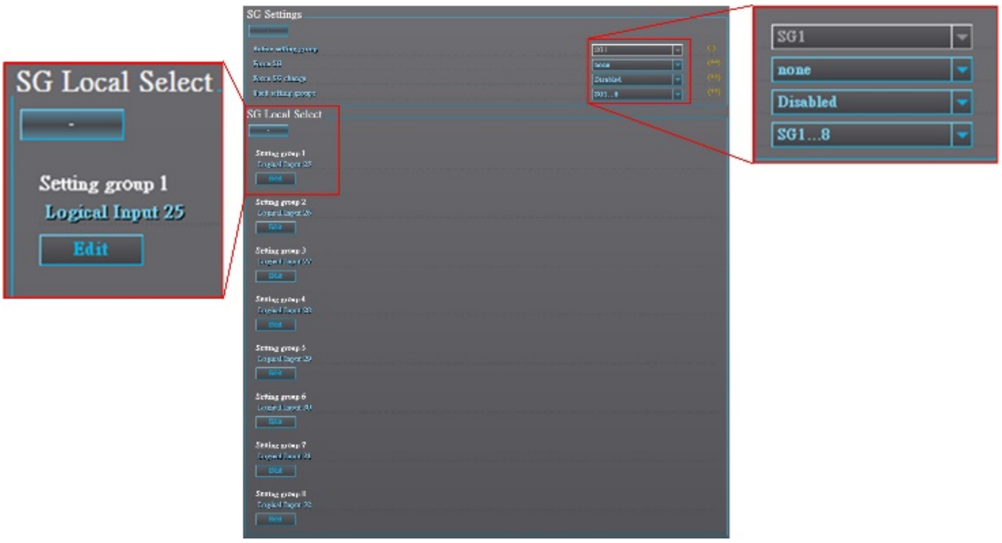

Fig. 4 Group setting of IED AQ-F215

III. Microgrid Protection Management System

In microgrid system, both utility and DGs provide fault current for fault point if a fault occurs. It causes that the flow direction of fault current is no longer unidirectional. Furthermore, the fault current provided by inverter of DGs is generally limited 1.2-2 times rated current [9]. IED will be nuisance tripping or no operation while a fault is occurring and cannot effectively isolate the fault.

In the work, the proposed MPMS depicted in Fig. 5 can monitor the topology framework of the microgrid via IEDs. IEDs are charge of monitoring the operation status of microgrid, which are power generation of DGs, switching status of each MC, the values of voltage and current in the transmission line and bus. The connection of the b-contact in MC with the DI terminal in IED can identify the switching status of MC.

The MPMS consists of three centers: information center, operation center, and policy center. The information center receives monitor information from IEDs with IEC 61850 communication protocol. Furthermore, based on each MC close or open, the work employs the Depth First Search approach [10] to detect the topology framework of the microgrid. From the topology framework, one can realize DGs, IEDs, and loads positions with respect to each other. In addition, either grid-connected mode or islanded mode can be identified. Operation center calculates the forward and reverse current of IEDs based on (1). As to the policy center, it makes the strategy how to switch properly the group setting to complete self-regulation and a comprehensive protection. Importantly, IEDs can effectively accomplish the fault isolation and increase the reliability. The working flowchart of the MPMS is illustrated in Fig. 6.

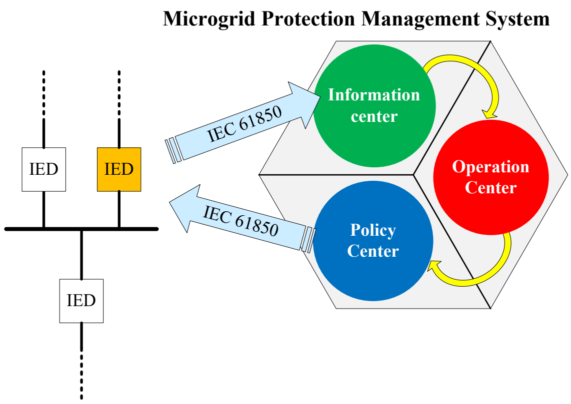

Fig. 5 A microgrid protection management system (MPMS)

IV. Simulation Results and Validation

Fig. 7 is the study model of microgrid with three zones 1, 2 and 3, which refers to the Institute of Nuclear Energy Research (INER) in Taoyuan, Taiwan. The IEDs are installed in DGs, loads, and transmission lines. The forward and reverse current of each IED are defined in Fig. 7. The capacity of DGs is listed in Table I. The simulation was performed using the Matlab/Simulink and Elipse Power Studio software.

Consider the microgrid in grid-connected. All the zones are connected to the utility, microturbines are disconnected from the microgrid, and energy storage system is in charge. The work simulated that the microgrid switches to islanded mode when the utility is fault. Table II is the status of the system operation under grid-connected. Table III is the forward and reverse current in IEDs, where the estimated current is computed by (1), and the pick-up current of the group setting is based on the percentage of the full load current.

As seen in Fig. 7, there is a fault in the line between Taipower system and BUS 1. The simulated fault current is listed in Table IV. The IED A06 detects 1220 A of the reverse fault current that is greater than 350 A of the pick-up value (in the first row and last column of Table III). Accordingly, the MC A06 trips, and the microgrid automatically switches to islanded mode. As mentioned earlier, the presented protection strategy is based on the GOOSE massages. Although all the reverse current in the third column of Table IV are greater than those of the last column of Table III, MCs A08, E01, C01, E02, C09, and E03 do not trip but the A06.

TABLE I
CAPACITY OF DGS IN FIG. 7

Zone 1						
DG	$\lceil T_1$	$HCPV_1$	PV_1	ESS_1	$Load_1$	$Load_2$
Capacity	65 kW	31.5 kW	20 kW	100 kVA	30 kW	30 kW

Zone 2							
DG	WT_1	$HCPV_2$	WT_2	ESS_2	$\lceil T_2$	$Load_3$	$Load_4$
Capacity	150 kW	60 kW	25 kW	125 kVA	65 kW	30 kW	30 kW

Zone 3					
DG	$HCPV_3$	WT_3	$\lceil T_3$	ESS_3	$Load_5$
Capacity	10 kW	3 kW	65 kW	125 kVA	30 kW

TABLE II
STATUS OF THE SYSTEM OPERATION UNDER GRID-CONNECTED

Zone 1	**Zone 2**	**Zone 3**
$HCPV_1$ 20 kW PV_1 12 kW	WT_1 75 kW $HCPV_2$ 37 kW WT_2 15 kW	$HCPV_3$ 6 kW WT_3 2 kW
$Load_{1+2}$ 60 kW ESS_1 10 kW	$Load_{3+4}$ 60 kW ESS_2 10 kW	$Load_5$ 30 kW ESS_3 10 kW

The energy storage system changes charge mode into supply mode for supplying continuous power. Furthermore, the microturbine unit may supply power, but it depends on the electricity demands. The MPMS changes the group setting of IEDs from SG 2 to SG 8 in response to alter operation mode. Table V is the alternative group setting with the different forward and reverse current. Compared with Table IV (grid-connected mode), it can be seen that both forward and reverse current in Table V (islanded mode) are less than those of the normal grid-connected operation are. The simulated fault current in the alternative group setting SG8 is listed in Table VI. The simulation results verify that the proposed MPMS can effectively isolate the fault, and the system reliability is greatly increased.

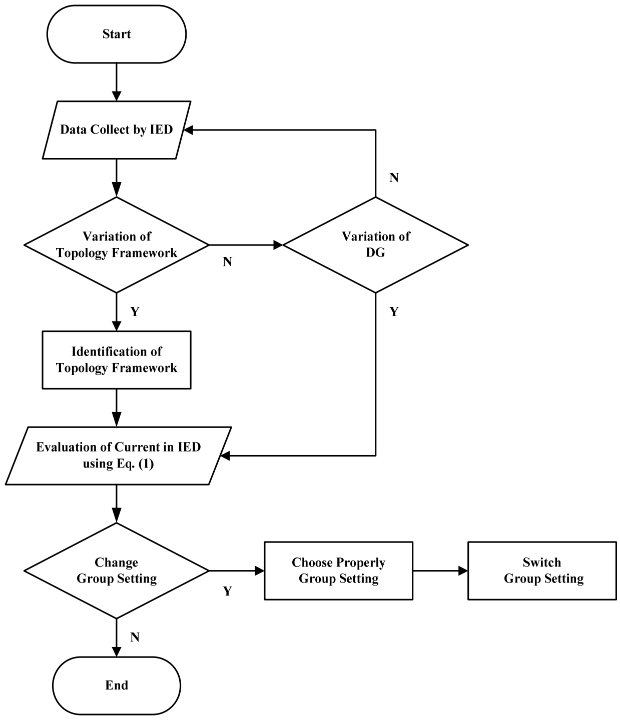

Fig. 6 Working flowchart of the MPMS

TABLE III
FORWARD AND REVERSE CURRENT UNDER NORMAL GRID-CONNECTED OPERATION

IED	Group	Forward Current		Reverse Current	
		Evaluation of Current in IED	Pick-up Current	Evaluation of Current in IED	Pick-up Current
A06	SG 2	1229	1000	361	350
A08	SG 2	1514	1000	77	115
E01	SG 2	1515	1000	77	80
C01	SG 2	1307	1000	284	332
E02	SG 2	1340	1000	251	224
C09	SG 2	1558	1000	33	108
E03	SG 2	1558	1000	33	107

V. CONCLUSION

The protection strategy of conventional power system is not applicable to microgrid because of the topology framework of microgrid is variation. The work used IED Arcteq AQ-F215 with eight group settings, IEC 61850 communication protocol, time synchronization protocol, and SCADA to build the MPMS. The MPMS performs the real time monitoring of microgrid topology, switches the group settings, and calculates the pick-up current of each IED. Provided there was a utility fault, simulation results verify that the proposed MPMS prevented the microgrid from failure. The microgrid exhibits the self-regulation for fault protection. The methods reported here could be beneficial to research attempting to robust the microgrid reliability.

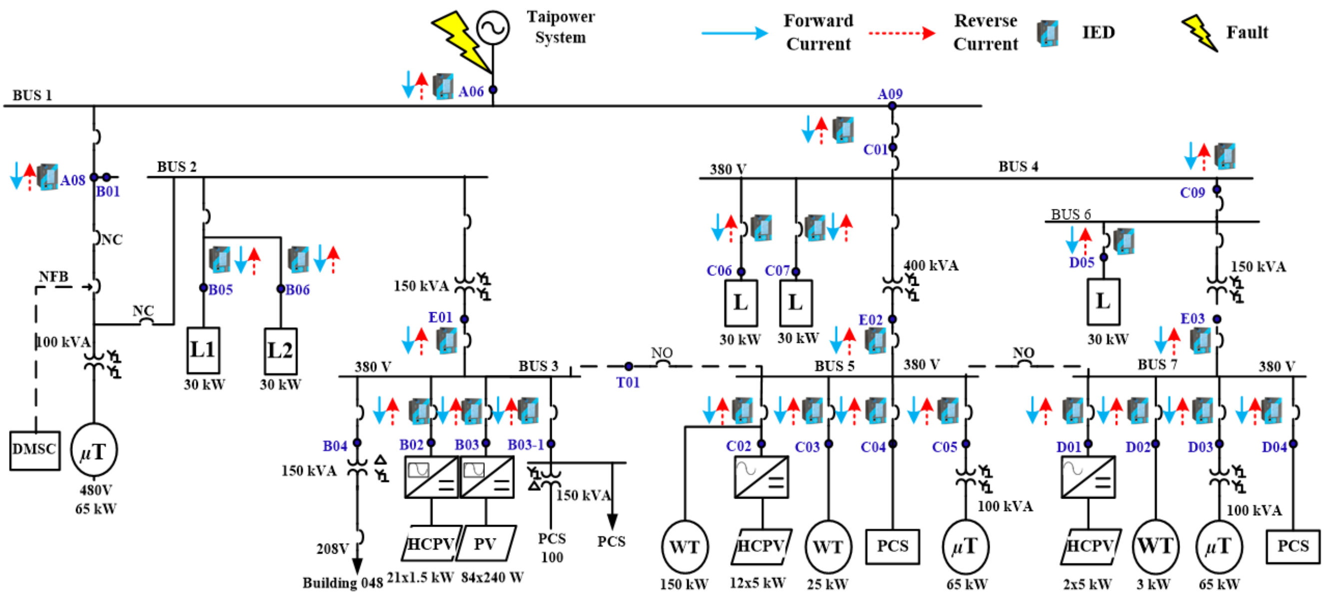

Fig. 7 Study model of the microgrid system

TABLE IV
SIMULATED FAULT CURRENT UNDER UTILITY FAULT

IED	Fault at Utility		Fault at Bus 1		Fault at Bus 2		Fault at Bus 4	
	Direction	Fault Current (A)	Direction	Fault Current (A)	Direction	Fault Current (A)	Direction	Fault Current (A)
A06	Reverse	1220	Forward	15880	Forward	4940	Forward	14360
A08	Reverse	257	Reverse	259	Forward	5030	Reverse	234
E01	Reverse	257	Reverse	259	Reverse	270	Reverse	234
C01	Reverse	966	Reverse	973	Reverse	302	Forward	14430
E02	Reverse	718	Reverse	723	Reverse	225	Reverse	728
C09	Reverse	248	Reverse	250	Reverse	78	Reverse	252
E03	Reverse	248	Reverse	250	Reverse	78	Reverse	252

TABLE V
FORWARD AND REVERSE CURRENT OF THE ALTERNATIVE GROUP SETTING AFTER UTILITY FAULT

IED	Group	Forward Current		Reverse Current	
		Evaluation of Current in IED	Pick-up Current	Evaluation of Current in IED	Pick-up Current
A06		Tripping			
A08	SG 8	250	333	106	115
E01	SG 8	250	368	106	80
C01	SG 8	106	115	250	333
E02	SG 8	120	223	236	225
C09	SG 8	342	341	14	107
E03	SG 8	342	341	14	107

TABLE VI
SIMULATED FAULT CURRENT OF THE ALTERNATIVE GROUP SETTING AFTER UTILITY FAULT

IED	Fault at Bus 1		Fault at Bus 2		Fault at Bus 4		Fault at Bus 6	
	Direction	Fault Current (A)	Direction	Fault Current (A)	Direction	Fault Current (A)	Direction	Fault Current (A)
A08	Reverse	259	Forward	845	Reverse	258	Reverse	256
E01	Reverse	259	Reverse	270	Reverse	258	Reverse	256
C01	Reverse	973	Reverse	845	Forward	258	Forward	256
E02	Reverse	723	Reverse	628	Reverse	728	Reverse	723
C09	Reverse	250	Reverse	217	Reverse	252	Forward	979
E03	Reverse	250	Reverse	217	Reverse	252	Reverse	252

ACKNOWLEDGMENT

The authors gratefully acknowledge the contributions of Jing-Min Wang, who is with the Department of Electrical Engineering, St. John's University, Taiwan, in writing assistance and commenting on the early draft.

REFERENCES

[1] A. K. Sahoo, "Protection of Microgrid through Coordinated Directional Over-current Relays," in Proceeding of Global Humanitarian Technology Conference, pp. 129-134, Trivandrum, 26-27 September, 2014.

[2] L. J. Jin, M. M. Jiang, and G. Y. Yang, "Fault Analysis of Microgrid and Adaptive Distance Protection Based on Complex Wavelet Transform," in Proceeding of Electronics and Application Conference and Exposition (PEAC), pp. 360-364, Shanghai, 5-8 November, 2014.

[3] S. M. Brahma, J. Trejo, and J. Stamp, "Insight into Microgrid Protection," in Proceeding of Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), pp. 1-6, Istanbul, 12-15 October, 2014.

[4] M. A. Zamani, T. S. Sidhu, and A. Yazdani, "A Protection Strategy and Microprocessor-Based Relay for Low-Voltage Microgrids," IEEE Transactions on Power Delivery, Vol. 26, No. 3, pp. 1873-1883, July, 2011.

[5] W. K. A. Najy, H. H. Zeineldin, and W. L. Woon, "Optimal Protection Coordination for Microgrids with Grid-Connected and Islanded Capability," IEEE Transactions on Industrial Electronics, Vol. 60, No. 4, pp. 1668-1677, April, 2013.

[6] S.-K. Huang, "Implementation of Protection Systems in Microgrids Based on IEC 61850 Communication," (in Traditional Chinese), M.S. thesis, Department of Electrical Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan, 2013.

[7] Y.-S. Huang, "Implementation of an IEC 61850 Based Protection Management Systems in Microgrids," (in Traditional Chinese), M.S. thesis, Department of Electrical Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan, 2014.

[8] T. S. Ustun, C. Ozansoy, and A. Ustun, "Fault Current Coefficient and Time Delay Assignment for Microgrid Protection System with Central Protection Unit," IEEE Transactions on Power Systems, Vol. 28, No. 2, pp.598-606, May, 2013.

[9] P. P. Barker and R. W. De Mello, "Determining the Impact of Distributed Generation on Power Systems. I. Radial Distribution Systems," in Power Engineering Society Summer Meeting, Vol. 3, pp. 1645–1656, Seattle, 16-20 July, 2000.

[10] X. Wang, "Research on Fault Reconstruction Technology of Micro-grid," (in Simplified Chinese), M.S. thesis, China Three Gorges University, Yichang, P.R.China, 2013.