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Relay Curve Selection Approach for Microgrid Optimal Protection

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Abstract- Islanded and grid-connected are two working modes for microgrids, which they impose some challenges on overcurrent protection scheme. Microgrid Short Circuit (SC) level is different in both modes which causes mal-operation of relays. Therefore, a new idea, relay, or method is necessary to solve this problem. This paper proposes a curve optimization approach for the microgrid protection. Directional Over Current Relays (DOCRs) have different kinds, depended on their parameters like standard inverse and extremely inverse. SC variation in two modes of microgrid can be compensated by appropriate relay curve selection. In this paper, DOCR curve optimization and selection are proposed for better protection coordination and microgrid protection. A hybrid Genetic Algorithm (GA) and linear programming method (LP) is also used for finding the optimal settings and the curve of relays. The proposed method is applied to Canadian distribution benchmark and modified IEEE 14 bus. The results indicate that the DOCR curve selection is an efficient tool for microgrid protection coordination and fast fault detection.

Keywords Genetic Algorithm, Microgrid Protection, Optimal Coordination, Relay characteristic curve, Linear Programming

1. Introduction

Microgrid is a new form of Distributed Generations (DGs) integration and operation. A microgrid can operate either in grid-connected or islanded mode. In grid-connected mode, microgrid interchanges power with the main grid, supplies peak load and tries to have economic operation. When a disturbance occurs in the main grid, microgrid isolates itself and continues to supply its own loads in the islanded mode. However, there are some challenges in microgrids protection.

Microgrid SC level is different in both modes. In grid-connected mode, main grid contributes to the fault current, whereas DGs supply fault current in the islanded mode of operation. It is also shown that the generator type of DGs is the main factor on DG fault current contribution. Synchronous Generators (SGs) have significant effect on SC level, inverter based DGs inject low fault currents.

Inverter output harmonic distortion is used for fault detection for inverter based microgrids [1]. A communication assistant digital relay for microgrid protection is also introduced [2]. A similar approach for multilevel protection scheme by using power line carrier and differential protection is proposed [3]. A differential scheme for microgrid feeder protection is also employed [4]. Central protection unit is another solution for microgrid protection [5-8]. A differential energy approach is proposed based on S transform and offline calculation is another proposed protection scheme for microgrid [9]. Energy calculation is investigated for microgrid protection [10]. Directional Over Current Relay (DOCR) coordination for a simple microgrid is obtained by Particle Swarm Optimization (PSO) [11]. Fault transient filtering by mathematical morphology filter is employed as key index for microgrid protection [12]. A microgrid protection system based on measurement and observation is proposed in [13]. A unidirectional Fault Current Limiter (FCL) is proposed in order to maintain microgrid upstream network protection coordination [14]. Adaptive DOCR relays coordination is employed for network protection. Proposed relays change their setting by sensing microgrid operating mode [15]. FCL allocation is another solution for SC variation of microgrid between grid-connected and islanded mode [16]. FCL impedance and DOCRs are optimally tuned by PSO and GA.

Protection coordination is performed by using optimization based methods or topology based methods. Topology based methods like graph theory and break point relaying are usually employed for heavily meshed networks [17-18]. In optimization based methods, the problem is formulated as an objective function. Several linear, non-linear and heuristic methods are also used in optimal protection coordination in papers [19-24]. In this paper, an optimization method is used for protection coordination of microgrid. Most of the previous methods use communication link which adds more cost on protection scheme. In addition, there would be some concerns about the communication link failure and protection system reliability. Some of the proposed methods are complex, imposing the high computational task on relays. FCL employment for microgrid protection increases fault clearing time and protection system cost.

In this paper, the DOCR characteristic curve is focused and its effect on coordination is investigated. SC level change of microgrid can be compensated to some extent by selecting an appropriate curve. Protection coordination of the microgrid is extended to include DOCR curve and parameters. A hybrid GA-LP is used to find the optimum curve and settings of relays. It is shown that choosing optimum curve can decrease fault detection time and satisfies protection constraints without any need to FCLs.

The next section provides a formulation of the microgrid protection system using FCL. The proposed approach is introduced in section 3. In section 4, curve approach is used for optimal protection coordination of case study microgrids and results are presented.

2. Microgrid Protection Coordination

Microgrid protection is faced with two main challenges. First, the low SC capability of inverter based DGs and the latter, SC level variation between modes of operation. In this paper, synchronous DGs based microgrid is considered. Only the latter problem is dealt in this paper. This problem is illustrated in Fig. 1. As seen, due to high fault currents in grid-connected mode, protection coordination may be violated.

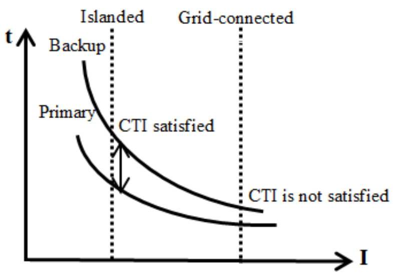

Fig. 1. Miss-coordination of DOCRs in microgrid

The DOCR coordination problem is formulated as an objective with relevant constraints. Objective function of DOCRs coordination for microgrid protection is presented in Eq. (1).

$$\min \sum_{m=1}^{2} \sum_{f=1}^{f_{max}} \left(\sum_{i} \left(t_i + \sum_{j} t_{ij}\right)\right) \tag{1}$$

Where i represents for primary relays and j for back up relays. f is fault location indices and t denotes relay operation time. m represents microgrid operation mode, one for grid-connected and two for islanded mode. Operation time of DOCRs is determined by Eq. (2).

$$t = \frac{A \times TDS}{\left(\frac{I_f}{I_p}\right)^B - 1} \tag{2}$$

Where If is fault current seen by relay, TDS is relay Time Dial Setting (TDS) and Ip is relay pick up current. Optimal protection coordination of DOCRs tries to reach the minimum operation time. A and B are DOCRs parameters which determine relays characteristic curves. Three main classes of relays are listed in Table 1. Mathematically, it can be written as Eq. (3).

$$(A, B) \epsilon \{(0.14, 0.02), (33.5, 1), (80,2)\} \tag{3}$$

During optimization, Coordination Time Interval (CTI) constraint must be satisfied. CTI constraint is shown in Eq. (4). Operation time of back up relay must lag enough to satisfy coordination constraint.

$$t_{ij}^{f} - t_i^{f} \geq CTI \tag{4}$$

One reasonable solution is FCL allocation. FCL limits main grid fault contribution in grid connected mode. FCL effect is shown in Fig. 2. As seen, SC change is settled down, but FCL allocation increases relays operating times.

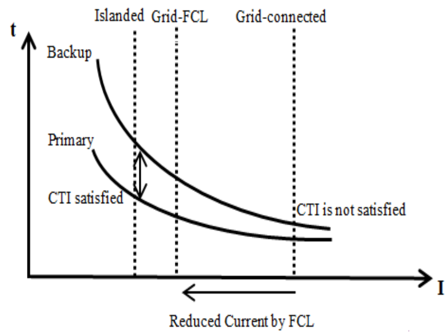

Fig. 2. Microgrid protection by FCL and DOCRs

Table 1. Three main OCR curves

OCR parameters	Name
A=0.14, B=0.02	Standard inverse OCR
A=33.5, B=2	Moderate inverse OCR
A=80, B=2	Extremely inverse OCR

3. Curve Selection Approach

As mentioned before, the microgrid protection system must detect and isolate faults in both modes of operation. The main obstacle in achieving good protection is SC level change in two modes.

Each DOCR has two parameters (A,B) and two settings (TDS,Ip) as shown in (2). The DOCRs settings are determined by performing protection coordination using the optimization methods. A and B determine relay class and characteristic curve. These characteristic curves for same settings of TDS and Ip are plotted in Fig. 3. A and TDS move relay curve up or down. Pickup current shifts curve right or left along current axis. DOCR parameter B changes the slope of the curve. All common OCRs have two features. Their operation time decreases with an increase in current and their curve have asymptote at the vicinity of load current. Infinite relay curves can be defined which all of them are inverse and they do not trip load currents. Each different pair of A and B leads to a new curve.

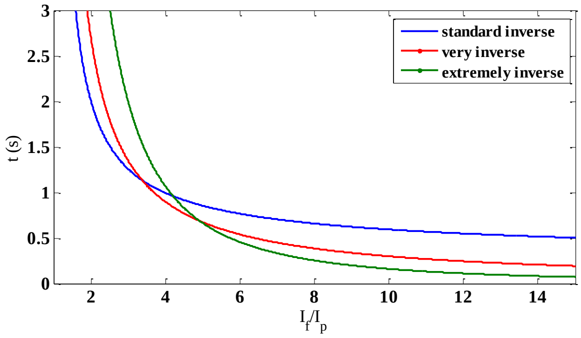

Fig. 3. Different DOCR curves

Depending on the network and fault currents seen by relays, some curves achieve better coordination. The best defined curve has no CTI violation and DOCRs operation time has the lowest value in comparison to other curves. By using Variable A and B, freedom degree of protection coordination increases and the search space of the problem is enlarged for finding appropriate settings. Fig. 4 represents the effect of the appropriate curve selection for relays. As shown, One pair is defined with suitable curve and satisfies CTI in both modes of operations.

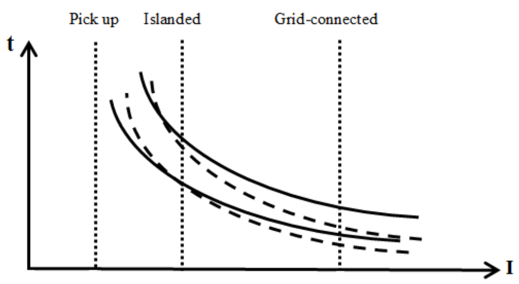

Fig. 4. SC level change compensation by curve selection

Therefore, fixed and pre-known values of A and B is not used and they are selected from an interval as shown in Eq. (5). Optimum values of A and B is dependent on network topology and specifications and varies from one network to another.

$$0.14 \le A \le 80, 0.02 \le B \le 2 \quad (5)$$

In conventional coordination, for a microgrid with N DOCR, the 2n+1 parameter, including FCL impedance, should be obtained while the relay curve is also unknown in the proposed method and 2n+3 parameter should be determined. Fig. 5 compares the solution vector for conventional and the new proposed method.

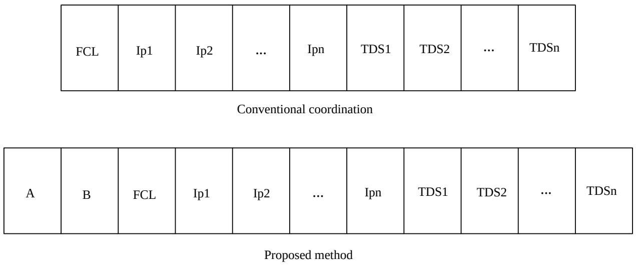

Fig. 5. Solution for conventional and the proposed method

In proposed technique, relay parameters A and B are added to the optimization problem. For each pair of (A,B), a solution like S can be found as shown in Eq. (6). The obtained optimum answer can be easily found by comparing the total operating time of each solution.

$$S = \begin{bmatrix} \alpha_1 & \beta_1 & \vdots & S_1^{'} \\ \alpha_2 & \beta_2 & \vdots & S_2^{'} \\ \vdots & \vdots & \vdots & \vdots \\ \alpha_n & \beta_n & \vdots & S_n^{'} \end{bmatrix} \quad (6)$$

Optimal protection coordination problem should be used for each pair and an exhaustive search should be performed. Hence, a hybrid LP and GA is used for better convergence as reported in [24]. The flowchart of hybrid GA-LP for the curve selection approach is depicted in Fig. 6.

As seen in Fig 6, by using the hybrid GA-LP, the solution vector is divided into two different parts. The one part includes Ip and FCL impedance, which turn the coordination formulation to a non-linear optimization. When these value are known, A and TDS can be obtained through linear programming solvers. Thus, the genetic algorithm tries to reach to the optimal set of Ip and FCL and linear programming finds the optimum A and TDS for Ip and FCL impedance set.

4. Simulation Results

Two case study systems are studied in this section. The Canadian benchmark for distribution system is shown in Fig. 7. The Lines impedance is 0.15+j0.15 ohm/km. DGs are 3 MVA 480 V, connected via 12.47/0.48 kV to the network. DOCR coordination for this microgrid is solved by curve selection approach. No FCL is considered. The results are plotted in Fig. 8.

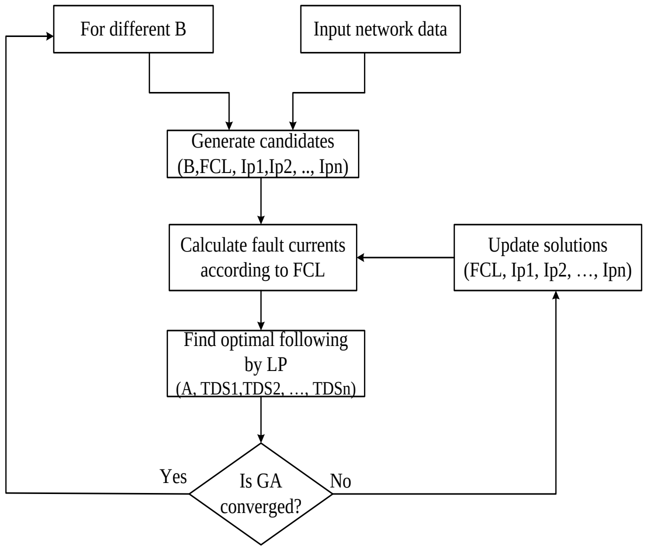

Fig. 6. Hybrid GA-LP for optimal relay curve selection

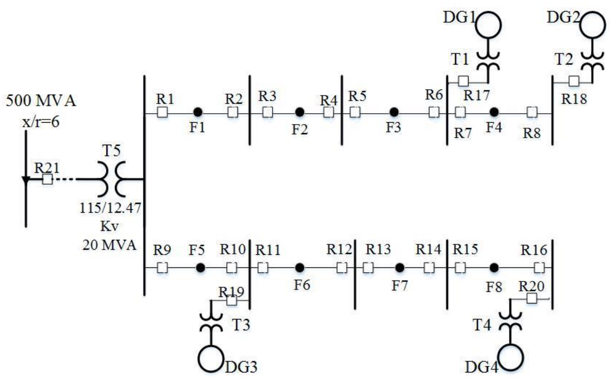

Fig. 7. First case study Microgrid

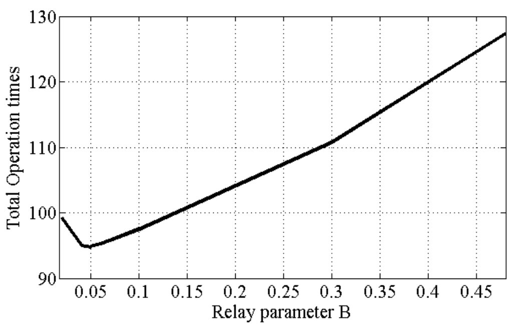

Fig. 8. Curve selection results for first case study

The results illustrate that the valid ranges of B lie between 0.02 and 0.15. Minimum operation times is 94.834 s, and optimum curve parameters are α = 0.1447 & β = 0.05. In the next scenario, microgrid is protected using FCL and four different curves. The results are given in Table 2. FCL and optimum curve is the best solution with total operating times of 67.57 s. In this case study, the standard inverse curve was close to optimum curve, hence only 14% reduction in operating times is observed (from 78.03 to 67.57 s), while in comparison to moderate and fast inverse curves, the operating times reduction seems satisfactory. Table 3 lists optimal settings of DOCRs for this netowk. Table 4 shows relays operating times for some faults for optimum curve protection. In this case, curve and FCL are not optimized together.

Table 2. Total operation times of relays for different curves

DOCR parameters	FCL (pu)	Total Operating time(s)
Standard inverse	3.6481	78.03
Moderate inverse	4.1087	90.69
Fast inverse	3.7188	100.07
Optimum curve	4.2891	67.57

Table 3. DOCRs optimal settings for optimum curve and FCL employment

Relay No	Ip	TDS	Relay No	Ip	TDS
R1	0.0893	0.4489	R11	0.1428	0.2745
R2	0.1488	0.3675	R12	0.1428	0.1784
R3	0.0648	0.3602	R13	0.074	0.2097
R4	0.108	0.5808	R14	0.074	0.5225
R5	0.0713	0.1871	R15	0.0355	0.05
R6	0.1188	0.6348	R16	0.0592	0.7262
R7	0.0355	0.05	R17	0.072	0.6259
R8	0.0592	0.7298	R18	0.12	0.389
R9	0.0893	0.44	R19	0.072	0.4778
R10	0.1488	0.3785	R20	0.072	0.7008
R21	0.1786	0.05			

Table 4. Relays operation times (s), (optimum curve & FCL)

		Primary relays	Backup relays
F1	Grid mode	0.6219, 0.9626	0.8862, 1.1626
	Islanded	0.7817, 0.9626	0.8817, 1.1626
F2	Grid mode	0.4322, 1.1449	0.6322, 1.3448
	Islanded	0.5241, 1.1449	0.7925, 1.3448
F5	Grid mode	0.6165, 0.9627	0.8869,1.1630, 1.1628
	Islanded	0.7821, 0.9627	0.8822,1.1430, 1.1628

The previous case study network was a simple radial distribution network. Modified IEEE 14 bus network is also studied as a looped microgrid. Modified system is shown in Fig. 9. Five DGs are added to the system which all of them are synchronous with 7 MVA capacity and transient reactance of 0.2 pu. DGs are connected to 20 kV through a set up 0.05 pu, 8 MVA transformer. Case study network is connected to the main grid through bus 1. In the islanded mode, it is assumed that microgrid sheds 40% of its load.

In the first scenario, optimal protection coordination is performed by FCL and standard inverse relays. Total operating times of DOCRs is 147.2079 s. the convergence of hybrid GA-LP for this scenario is plotted in Fig. 10. The optimal settings of relays are also presented in Table 5. FCL impedance is obtained 2.4442 pu.

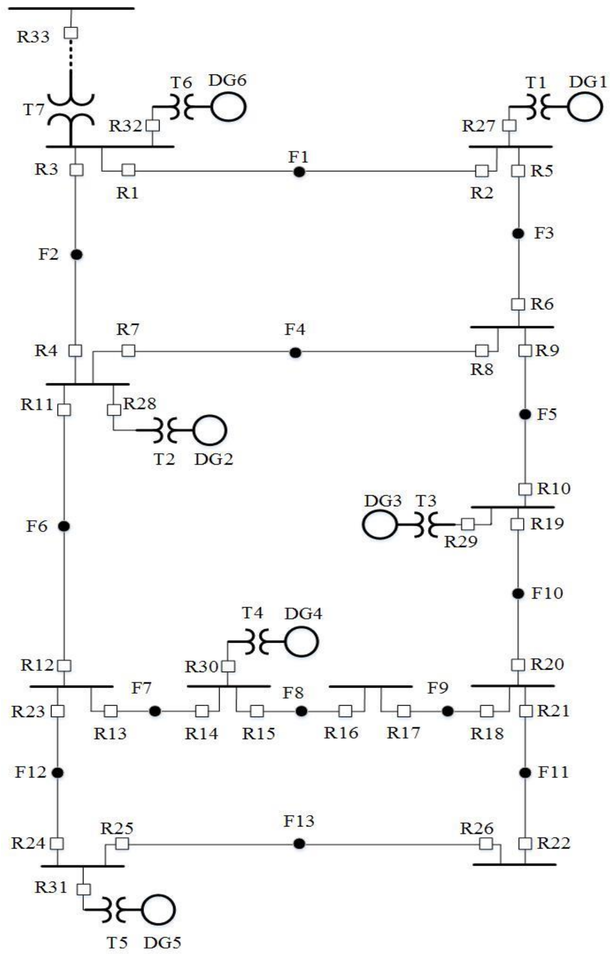

Fig. 9. Second case study microgrid

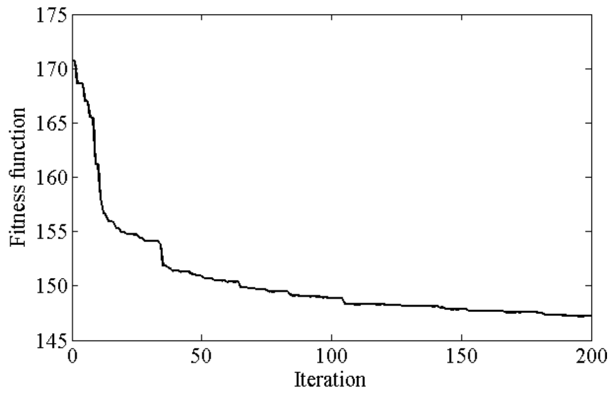

Fig. 10. hybrid GA-LP for FCL & standard inverse relays

Table 5. Optimal settings of relays for standard inverse and FCL

	TDS	Ip		TDS	Ip
R1	0.182	0.1647	R17	0.0655	0.0655
R2	0.1464	0.1774	R18	0.0643	0.0643
R3	0.2106	0.1444	R19	0.0256	0.0256
R4	0.1032	0.2655	R20	0.0251	0.0251
R5	0.2265	0.1624	R21	0.0444	0.0444
R6	0.1327	0.164	R22	0.0461	0.0461
R7	0.3417	0.0723	R23	0.0407	0.0407
R8	0.2391	0.0724	R24	0.0412	0.0412
R9	0.256	0.1835	R25	0.0526	0.0526
R10	0.1264	0.1805	R26	0.0529	0.0529
R11	0.2491	0.1537	R27	0.0648	0.0848
R12	0.1271	0.1556	R28	0.0716	0.0916
R13	0.2456	0.1506	R29	0.1111	0.1111
R14	0.1556	0.1529	R30	0.0961	0.0961
R15	0.3534	0.0574	R31	0.0676	0.0876
R16	0.2653	0.0586	R32	0.0668	0.0868
R33	0.05	0.2433	FCL=2.4442 pu		

Moreover, Protection coordination with curve selection approach and FCL is also applied to this case study. Table 6 displays optimum settings of relays and the optimum curve is estimated $\alpha = 1.2088$ & $\beta = 0.26$ and FCL impedance is 2.5654 pu. Total operating times of relays is 119.96 which show 18.5% reduction in comparison to standard relays and FCL case with total operating times of 147.21s. In average, operating time of each relay is decreased about 170 ms. Relays operating times for different faults are given in Table 7.

Table 6. Optimal settings of relays for optimum curve-FCL

	TDM	Ip		TDM	Ip
R1	0.2411	0.1768	R17	0.4219	0.0666
R2	0.2031	0.1773	R18	0.5498	0.0665
R3	0.2599	0.1768	R19	0.9969	0.0267
R4	0.1358	0.2674	R20	0.6119	0.0273
R5	0.3317	0.1642	R21	0.6586	0.0457
R6	0.1843	0.1657	R22	0.3718	0.0477
R7	0.5676	0.0695	R23	0.6485	0.0413
R8	0.3714	0.0708	R24	0.5465	0.0409
R9	0.3905	0.1812	R25	0.4938	0.0527
R10	0.1759	0.1812	R26	0.4718	0.0468
R11	0.3815	0.1551	R27	0.5131	0.0675
R12	0.1758	0.1535	R28	0.3684	0.0654
R13	0.3737	0.1537	R29	0.2275	0.119
R14	0.2109	0.1542	R30	0.2243	0.1123
R15	0.6211	0.0568	R31	0.3412	0.0675

R16	0.4261	0.0572	R32	0.3245	0.0749
R33	0.05	0.2452	FCL= 2.5654		

Table 7. Optimum operation time of relays (s)

Islanded Faults	Primary relays		Backup relays					
F1	0.5663	0.4478	0.7663	0.6807	0.9573	0.8794		
F2	0.3722	0.6725	0.6491	0.8725	0.8746	0.9113	0.9079	
F3	0.3708	0.7513	0.5708	0.9513	1.1900	1.2979		
F4	0.4781	0.6935	0.6918	0.8935	0.9006	1.5575	1.8423	
F5	0.4298	0.8125	0.6372	0.9317	1.0188	1.0833		
F6	0.3966	0.7066	0.7609	0.9066	0.9234	1.1939		
F7	0.4774	0.7017	0.7013	0.8594	0.9017	0.9604		
F8	0.5322	0.6688	0.7499	0.8688	0.9263			
F9	0.5973	0.6205	0.8053	0.8268	0.8299			
F10	0.5330	0.7429	0.7495	0.7542	0.9429	1.0332		
F11	0.5159	0.5980	0.7251	0.8508	0.8742			
F12	0.5767	0.6353	0.7820	0.8353	0.8808	1.003		
F13	0.5352	0.5525	0.7578	0.8078	0.8540			
Grid- Faults	Primary relays		Backup relays					
F1	0.4375	0.4740	0.6375	0.8737	0.8956	0.9559	1.0197	
F2	0.3632	0.5441	0.6390	0.8592	0.8886	0.9100	0.9890	1.1403
F3	0.3500	0.6707	0.5557	0.8707	0.9596	1.0627		
F4	0.4544	0.6466	0.6863	0.9099	0.9399	1.0505	1.2365	
F5	0.4142	0.7293	0.6142	0.9293	0.9337	0.9651		
F6	0.3827	0.6401	0.7192	0.8401	0.8698	0.8944	0.9187	
F7	0.4552	0.6493	0.6552	0.8493	0.8845	0.8618		
F8	0.5043	0.6412	0.7043	0.8412	0.8729			
F9	0.5696	0.5897	0.7696	0.7897	0.7908			
F10	0.5145	0.7078	0.7144	0.7208	0.9078	0.9496		
F11	0.4953	0.5770	0.6953	0.8114	0.8320			
F12	0.5493	0.6170	0.7493	0.8170	0.8377	0.8807		
F13	0.5160	0.5270	0.7160	0.7270	0.8589			

5. Conclusion

In this paper, a new approach for microgrid protection is proposed. Relay parameters are added to optimization problem variables which called curve selection approach. Selection of the optimal relay curve helps to CTI constraint satisfaction and decreases relays operation times. Curve selection helps fast fault detection, especially in microgrid where there are low fault currents in the islanded mode and the relays should work in both modes appropriately. A hybrid GA-LP method is used to obtain the optimum curve, FCL impedance and relays settings.

References

[1] H.H. Al-Nasseri , M.A. Redfern, “Harmonic content based protection scheme for microgrids dominated by solid state converters”, power system conference MEPCON 2008, pp. 50-56. DOI: 10.1109/MEPCON.2008.4562361

[2] E.Sortomme, M. Venkata M, J. Mitra "Microgrid protection using communication-assisted digital relays", IEEE Transaction on Power Delivery; 25(4), pp. 2789-2796, 2010. DOI: 10.1109/TPWRD.2009.2035810
[3] A. Prasai, Du Yi, A. Paquette, "Protection of meshed microgrids with communication overlay", Energy Conversion Congress and Exposition (ECCE) 2010: pp. 64-71.DOI: 10.1109/ECCE.2010.5618074
[4] M. Dewadasa, A. Ghosh, G. Ledwich, "Protection of microgrids using differential relays", 21st Australasian Universities Power Engineering Conference (AUPEC) 2011: 1-6.
[5] Y. Han, X. Hu, D. Zhang, "Study on applying wavelet transform to the protection algorithm of microgrid dominated by inverter -interfaced DGs", International Conference on Power System Technology (POWERCON) 2010: pp. 1-6. DOI: 10.1109/POWERCON.2010.5666119
[6] T.S. Ustun, C. Ozansoy, A. Zayegh, "A central microgrid protection system for networks with fault current limiters", 10th International Conference on Environment and Electrical Engineering (EEEIC) 2011: pp. 1-4.DOI: 10.1109/EEEIC.2011.5874575
[7] T.S. Ustun, C. Ozansoy, A. Zayegh, "A microgrid protection system with central protection unit and extensive communication", 10th International Conference on Environment and Electrical Engineering (EEEIC) 2011: pp.1-4. DOI: 10.1109/EEEIC.2011.5874777
[8] T.S. Ustun, C.Ozansoy, A. Zayegh, "Modeling of a centralized microgrid protection system and distributed energy resources according to IEC 61850-7-420", IEEE Transaction on Power System 2012; 27(3): 1560-1567. DOI: 10.1109/TPWRS.2012.2185072
[9] T.S. Ustun, C. Ozansoy, A.Ustun , "Fault current coefficient and time delay assignment for microgrid protection system with central protection unit", IEEE Transaction on Power System 2013; 28(2): 598-606. DOI: 10.1109/TPWRS.2012.2214489
[10] S.R. Samantaray, G. Joos, I. Kamwa, "Differential energy based microgrid protection against fault conditions", IEEE PES Innovative Smart Grid Technologies (ISGT) 2012: 1-7. DOI: 10.1109/ISGT.2012.6175532
[11] Y. Damchi, H.R. Mashhadi, J. Sadeh, "Optimal coordination of directional overcurrent relays in a microgrid system using a hybrid particle swarm optimization", Advanced Power System Automation and Protection (APAP) 2011: 1135-1138. DOI: 10.1109/APAP.2011.6180976
[12] X. Li, A. Dysko, G Burt, "Enhanced protection for inverter dominated microgrid using transient fault information", Developments in Power Systems Protection DPSP 2012: 1-5. DOI: 10.1049/cp.2012.0081
[13] M. Esreraig, J. Mitra, "Microgrid protection using system observer and minimum measurement set," International Transactions on Electrical Energy Systems 2013. DOI: 10.1002/etep.1849
[14] T. Ghanbari, E. Farjah, "Unidirectional fault current limiter: An efficient interface between the microgrid and main network", IEEE Transaction on Power System 2013, 28(2): 1591-1598. DOI: 10.1109/TPWRS.2012.2212728
[15] C. Buque, O. Ipinnimo O, S. Chowdhury, "Modeling and simulation of an Adaptive Relaying Scheme for a Microgrid", Power and Energy Society General Meeting 2012: 1-8. DOI: 10.1109/PESGM.2012.6344569
[16] W.K.A. Najy, H.H. Zeineldin, W.L. Woon, "Optimal protection coordination for microgrids with grid-connected and islanded capability", IEEE Transaction. Industrial Electronics 2013, 60(4): 1668-1677. DOI: 10.1109/TIE.2012.2192893
[17] H. Sharifian, H. Askarian Abyaneh, S. Salman, R. Mohammadi, "Determination of the minimum break point set using expert system and genetic algorithm," IEEE Transaction on Power Delivery 2010; 25(3) : 1284–1295. DOI: 10.1109/TPWRD.2010.2043999
[18] Q. Yue, F. Lu, W Yu, J.Wang J, "A novel algorithm to determine minimum break point set for optimum cooperation of directional protection relays in multi loop networks," IEEE Transaction on Power Delivery 2006, 21(3) : 1114–1119. DOI: 0.1109/TPWRD.2005.861333
[19] M. Mansour, S. Mekhamer, N.S. El-Kharbawe, "A modified particle swarm optimizer for the coordination of directional overcurrent relays," IEEE Transaction on Power Delivery 2007, 22(3): 1400–1410. DOI: 10.1109/TPWRD.2007.899259
[20] P.P. Bedekar, S.R. Bhide, "Optimum coordination of directional overcurrent relays using the hybrid GA-NLP approach," IEEE Trans. Power Delivery 2011, 26(1): 109–119. DOI: 10.1109/TPWRD.2010.2080289
[21] C So, K Li, "Time coordination method for power system protection by evolutionary algorithm," IEEE Transaction on Industrial Application 2000, 36(5): 1235–1240. DOI: 10.1109/28.871269
[22] M. Barzegari, S. Bathaee S, M. Alizadeh, "Optimal coordination of directional overcurrent relays using harmony search algorithm," in Proc. 9th Int. Conf Enviroment and electrical engineering EEEIC 2010, 321–324. DOI: 10.1109/EEEIC.2010.5489935
[23] H. Yang, F. Wen, G. Ledwich, "Optimal coordination of overcurrent relays in distribution systems with distributed generators based on differential evolution algorithm", International Transactions on Electrical Energy Systems 2013, 23(1): 1-12. DOI: 10.1002/etep.635
[24] A. Noghabi, J. Sadeh, H. Mashhadi, "Considering different network topologies in optimal overcurrent relay coordination using a hybrid GA," IEEE Transaction on Power Delivery 2009, 24 : 1857–1863. DOI: 10.1109/TPWRD.2009.2029057