International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
IJISAE
ISSN:2147-6799 www.ijisae.org Original Research Paper

An Artificial Intelligence Based Optimal Technique for Coordinating Multiple Setting Group Type Overcurrent Relays Considering Network with Renewable-Resources

Jaydeepsinh Sarvaiya[1*], Tejaskumar Pandya[2], Mehul Vala[3]

Submitted: 15/03/2024 **Revised**: 29/04/2024 **Accepted**: 05/05/2024

Abstract: Integrating renewable based resources with the network changes the power flow and makes relay coordination more complex and challenging. Looking at the supportive environment for renewable based distributed generation on the grid, the penetration of RE-based distributed generation continuously increases. Relay coordination optimization challenges are complex problems that involve several objectives and constraints to DGs. The aim is to minimize the operation time of each relay while ensuring that all relevant constraints are met. The coordination constraints consist of fulfilling the coordination time interval (CTI) and adhering to the time requirements for relay operations. In order to address coordination optimization problems, decision-making variables are established to minimize the objective function while ensuring that the essential constraints are satisfied. Most available research focuses on defining relay coordination for fixed network topologies. However, relay coordination varies in practice due to many factors, such as maintenance and element failures. Modern overcurrent relays can store multiple relay settings, but the number of settings they can store is limited compared to the vast network configurations. To address this, a suitable clustering technique like K-Means can be employed to group different network topologies using an appropriate clustering index. The target function and the constraints are both time-dependent, so the standard index fault current deviation is not used as the clustering index. Instead, time-dependent features like the average relay operational time are used. IEEE-14 bus system along with wind and solar type DG has been used to address the optimization problem.

Keywords: *Artificial Intelligence, Coordination time interval, K-Means, Distributed Generator, Renewable Energy, DOCR, Genetic Algorithm, DIgSILENT*

1. Introduction

The distribution network has evolved from passive to active with the introduction of Distributed Generation (DG). Although DG brings several benefits, it also introduces challenges, such as the complexity of relaying due to bidirectional current flow and varying fault current magnitudes. Overcurrent relays are commonly used to protect distribution networks. To ensure system reliability, backup relays, synchronized with primary relays, are placed alongside them.

TMS and PS are the key decision variables defined to solve relay coordination problems. Implementing an inverse time current characteristic helps address the limitations of time-graded and current-graded backup protection systems.

By selecting appropriate decision variables, the relay's time multiplier setting (TMS) and pickup current (IP) can be adjusted. Relay coordination can be achieved through a nonlinear programming technique, which allows flexibility in the values of the decision variables, or a linear programming method, which optimizes TMS values for given IP values. This research employs the nonlinear programming method for greater flexibility.

Moreover, each overcurrent relay is expected to store four distinct settings. This research aims to determine the optimal relay settings for various network topologies, though activating the correct settings for specific configurations is beyond its scope. The IEEE 14-bus system's distribution portion serves as the test system. Sixteen topologies are created based on hourly renewable energy generation. The K-Means clustering technique groups these topologies into four clusters based on fault current variance, with an optimal relay setting identified for each cluster. Simulations are conducted using PowerFactory DIgSILENT software, while clustering and optimization are performed using MATLAB.

Microgrids have garnered significant attention in recent years and have proven to be an essential asset in the electricity market. One of the key factors contributing to the popularity of microgrids is their capacity to integrate renewable power generation into the distribution system. A wide range of distributed generation (DG) technologies, such as sustainable micro-turbine generation, wind generation, photovoltaic generation, and energy storage systems, enhance the practicality of microgrids in both

[1]Electrical Engineering Department, Shantilal Shah Engineering College, Bhavnagar,Gujarat, India.*
[2]Electrical Engineering Department, Sir Bhavsinhji Polytechnic Institute, Bhavnagar,Gujarat, India.
[3]Electronics and Communication Department, Shantilal Shah Engineering College, Bhavnagar,Gujarat, India.
**Corresponding Author Email id: jbs201182@gmail.com.*

isolated and connected to the main power grid modes [1]. When attempting to fully utilize microgrids, there are multiple technical disputes that need to be addressed, and protection is one of the very difficult areas [2]. Several methods were proposed, driven by advancements in protective mechanisms. Microgrids that include distributed generation (DG) can lead to fluctuations in short circuit levels, which is a primary factor contributing to the difficulty faced in protecting these systems.

The capacity of microgrids to function independently from the primary utility can amplify these swings. Furthermore, the presence of several operational topologies adds complexity to the selection of protection measures[3-4].

The presence of distributed generation (DG) and various operational configurations primarily gives rise to the technical difficulties encountered by microgrids. The identification of protection concerns is crucial in effectively managing the operation of microgrids, necessitating the implementation of specific solutions[5]. Several primary protection challenges can be recognized as follows. In [6], The K-means technique is utilized to cluster different topologies resulting from N-1 contingencies, focusing on fault current magnitudes. Coordination challenges are addressed using nonlinear programming. An optimized relay setting is achieved through the hybrid water cycle-moth flame algorithm. The authors substantiated the efficacy of their approach through comparative analysis against various optimization methods, emphasizing its superior performance. In [7], the authors performed clustering on 14 topologies, resulting in various cluster based indices. The cluster based indices utilized in this investigation were qualities that varied with time. Another significant distinction was in the approach to problem framing employed. Clustering of various network topologies is performed using a distinct clustering approach called K-medoids [8]. Previous studies have commonly used pickup current as a clustering index. However, limitations include its applicability primarily to smaller datasets and the necessity of using K-means to initiate the clustering process. The primary focus of the research centered on cluster development rather than optimization techniques. The study compared the performance of three clustering methods—K-Means, Self-Organizing Mapping, and Hierarchical Clustering [9]. A distinct heuristic adjustment was proposed to select the optimal clustering approach, analyzing outcomes when partitioning all topologies into two, three, and four clusters. In [10], Principle Component Analysis (PCA) was integrated to enhance the effectiveness of the K-means algorithm. Addressing backup protection interference without communication means, [11] introduced a Time Current Voltage (TCV) characteristic for directional overcurrent relays (DOCRs). This concept was extended to Dual-setting DOCRs, accommodating two relay settings for forward and reverse fault currents [12]. Introducing a time-inverse relay model based on voltage and current in [13], authors considered fault current magnitude impact on relay operation time and conducted clustering based on DG penetration levels. Coordination challenges for Distributed Object Computing Runtimes (DOCRs) were addressed using standard relay characteristics [14]. Highlighting the potential for flexibility, [15] treated relay operating time constant as a variable for optimal coordination using traditional relay characteristics. [16] synchronized overcurrent relays with user-defined parameters, allowing for variation in upper limits of pickup current instead of fixing them. Comparing linear and nonlinear programming approaches in [17], authors concluded that Genetic Algorithms (GA) outperformed other optimization strategies. In [18] and [19], comprehensive evaluations of microgrid protection advancements included a comparison of adaptive protection systems and their pros and cons. Addressing relay coordination challenges arising from network changes and renewable energy fluctuations in [20], a hybrid PSO-ILP approach effectively coordinated multiple-setting group-type overcurrent relays. A hybrid GA was introduced in the same study to optimize objective functions under multiple coordination constraints. Analyzing maximum relay operation durations and OCR coordination limitations in [21], challenges were framed as the MNLP problem. Successful relay coordination using an enhanced firefly algorithm was demonstrated in [26]. Employing self-adaptive weighting, [27] defined relay coordination integrating dual-setting Time Current Voltage overcurrent relays. Considering uncertainties like simultaneous and single contingencies in [28], authors achieved relay coordination by assessing network operation in islanded or grid-linked mode. Coordination aimed to minimize the impact of DOCRs on operational activities, integrating DG allocation, planning, and protection in [29]. An overwhelming number of current research establishes ideal relay coordination for a specific amount of generations from REs that aren't really constant. Weather-related fluctuations cause the amount of generations from REs to fluctuate constantly, and an optimized relay setting designed for one quantity of generation may not function as well for another. To the best of the author's knowledge, no literature exists that uses nonlinear programming to formulate the problem and takes into account differences in the amount of generations from REs.

2. Research Method

In PowerFactory DIgSILENT software, the distribution segment of the IEEE 14-bus system is simulated using parameters detailed in [18]. Initially, only bus 06 in the original system featured 10 MW of synchronous generation. Additional 10 MW synchronous generation is planned for bus 09 to enhance Distributed Generation (DG) penetration. Renewable energy (RE) generation is allocated to bus 13 (solar) and bus 06 (wind). Detailed parameters of the generator at bus 09 are listed in Table 1. Figure 1 illustrates the test system layout, while Figure 2 depicts the simulated setup.The simulation defines 16 distinct network topologies based on varying RE generation levels, detailed in Table 1. Hourly meteorological data from NREL's official website is used to estimate RE generation, with solar output calculated using NREL's PV calculator and wind generation determined using NREL's wind calculator. .Following simulation, fault currents are calculated by simulating three-phase bolted faults near the relay, occurring at 4% of the line length. For each of the 16 defined topologies, near-end fault currents are computed, and the average fault current for each relay is determined. The deviation from the mean fault current is calculated for each topology, and the sum of these deviations across all 16 topologies serves as the clustering index for the process. This index is crucial for clustering the fault current deviations effectively..

Table 1. Network Topologies

Topology	Solar O/P in kW	WTG O/P in kW	Topology	Solar O/P in kW	WTG O/P in kW
T-1	0.00	645.13	**T-9**	2857.37	1770.23
T-2	0.00	330.30	**T-10**	3541.87	1770.23
T-3	0.00	1114.78	**T-11**	1307.05	1770.23
T-4	551.83	1114.78	**T-12**	1048.99	1770.23
T-5	1480.21	1114.78	**T-13**	716.18	1114.78
T-6	2421.20	1114.78	**T-14**	955.01	1114.78
T-7	3679.01	1770.23	**T-15**	77.67	1770.23
T-8	2519.35	1770.23	**T-16**	0.00	1770.23

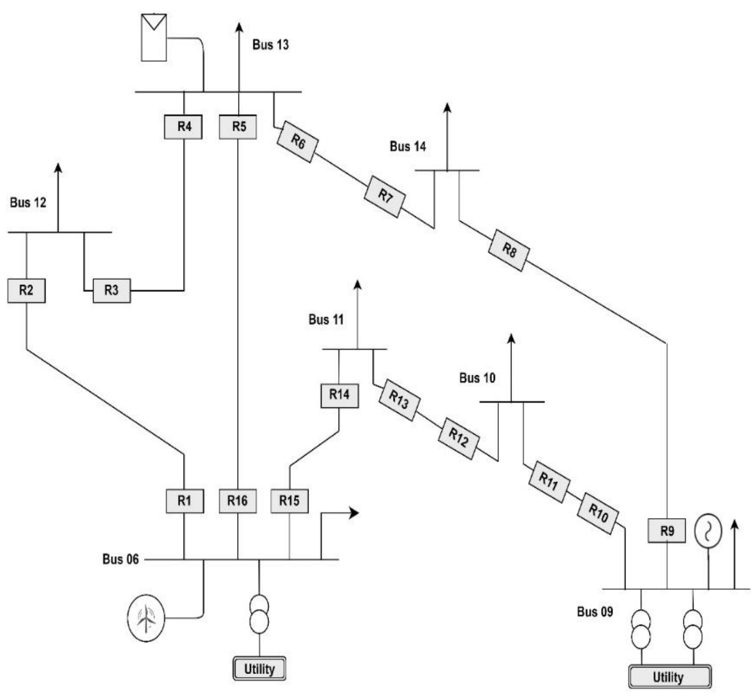

Fig 1 Network Configuration

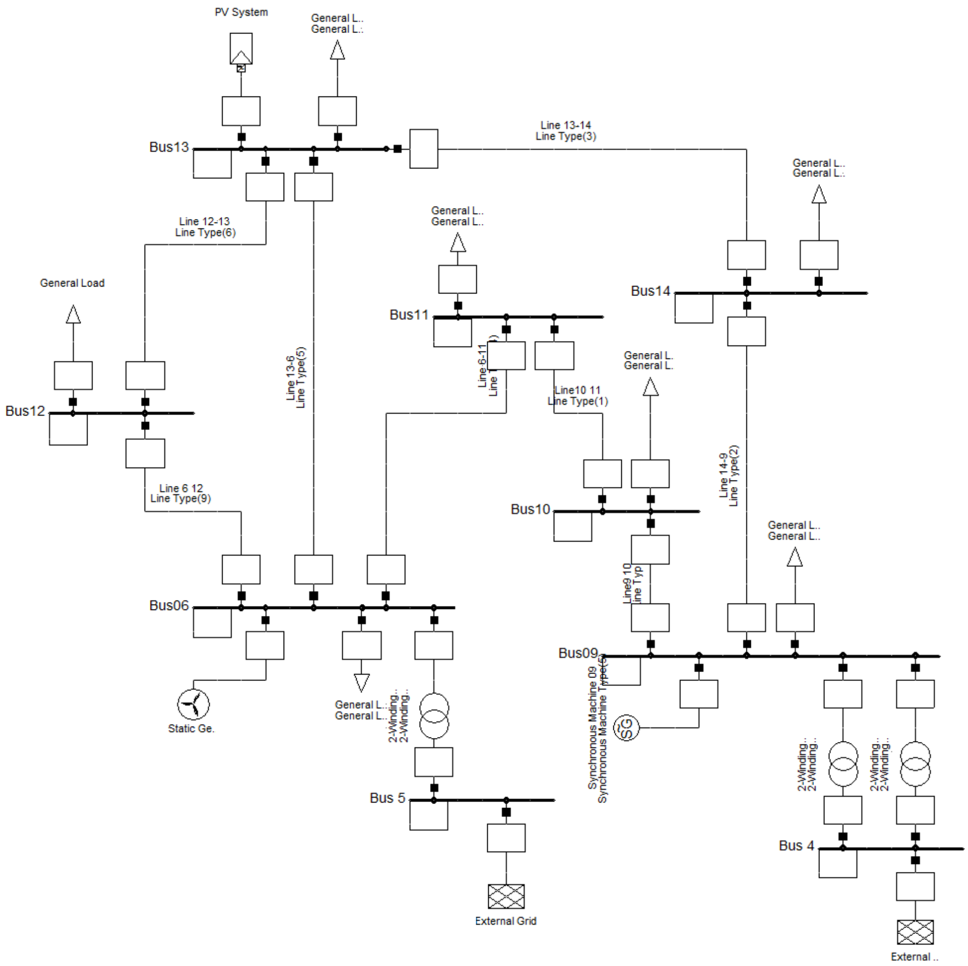

Fig 2 Simulated Test Network

When employing multiple-setting group-type overcurrent relays, the number of possible network topologies exceeds the capacity of relays to store settings. To manage this, similar groups of topologies are clustered together, each cluster optimized with a dedicated relay setting. The K-means algorithm is utilized for clustering comparable network topologies, effectively grouping data based on similarities within clusters while maintaining differences between them. This algorithm computes centroids based on Euclidean distances from cluster data points to assign N-dimensional data into K clusters.

In this study, 16 topologies are grouped into four clusters based on the sum of fault current deviations as the clustering index. Table 2 presents the formation of these four clusters: Cluster 1 accommodates two topologies, while Clusters 2 and 4 each include three topologies. Cluster 3 encompasses eight distinct topologies. The fault current deviations across all topologies range from -0.2561 to 0.2009. The centroids of the clusters are -0.2496, -0.1364, 0.0480, and 0.1749, respectively.

Table 2 Cluster Formation

Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**
T 7, T 10	T 9, T 8, T 6	T 11, T 12, T 5, T 14, T 13, T14, T 15, T 16	T3, T1, T2

Relay coordination optimization involves typical steps found in other optimization problems: defining an objective function, setting boundaries, and specifying constraints. A Genetic Algorithm (GA) from the MATLAB optimization toolbox is employed for this purpose. The optimization problem is structured into three main sections, as detailed below: Objective Function Construction, Boundary Definition, and Constraint Determination. It is assumed that all Directional Overcurrent Relays (DOCRs) used are of the Standard Inverse type.

The objective function of the problem aggregates the operating times of all primary relays, depicted in equation

(1), with the aim to minimize this function. The operating time of an overcurrent relay can be computed using equation (2).

$$O.F. = \Sigma t_k;\ k=1,2,3,\ldots,16 \quad (1)$$

$$T_k = TMS * \frac{A}{(\frac{I_f}{I_p})^{B}-1} \quad (2)$$

Tk denotes the operational time of the kth primary relay, whereas TMS, If, and IP represent the relay's time Multiplier Setting, Fault Current, and Pickup Current, respectively. Table 3 displays the values of relay characteristic constants according to IEC-60255 STD.

Table 3 Relay characteristic constants values as per IEC-60255 standard.

Relay Characteristic Curve	**A**	**B**
Standard- Inverse (SI)	0.114	0.02
Very -Inverse (VI)	12.5	1
Extremely- Inverse (EI)	78	2

The nonlinear programming approach is utilized to minimize the problem in this test system, necessitating the definition of 32 variables within specified bounds. Sixteen variables are allocated for the Time Multiplier Setting (TMS) of each relay, with bounds typically set by manufacturers. In this case, TMS values between 0.05 and 1.1 are acceptable for all relays.

Additionally, each of the sixteen relays requires an additional sixteen variables for their Pickup Current settings. Unlike TMS, Pickup Current bounds for each relay must be individually determined. The upper bound of Pickup Current is determined by the short circuit current, while the lower bound is set by the rated current. Specifically, the lower bound is 1.5 times the rated current, and the upper bound is 65% of the minimum short circuit current, as expressed in equations (4) and (5) respectively.

All relays must have their Pickup Currents within the range defined in equation (6).

$0.05 <= TMSm <= 1.1;\ m = 1,2,3,\ldots,16$ (3)

$I_{Pminm} = 1.5\ I_{Lm};\ m = 1,2,3,\ldots,16$ (4)

$I_{Pmaxm} = 2/3\ I_{SCm}\ ;\ m = 1,2,3,\ldots,16$ (5)

$I_{Pminm} < = I_{Pm} < = I_{Pmaxm};\ m = 1,2,3,\ldots,16$ (6)

While I_{Pminm} and I_{Pmaxm} indicate the lower and maximum pickup current limits of m^{th} relay, I_{Lm} and I_{SCm} represent the rated current and short circuit current flowing through m^{th} relay.

When optimizing relay coordination, two critical constraints are considered: Coordination Time Interval (CTI) and relay operating time boundaries. During a fault event, the primary relay detects the fault and sends a trip signal to the corresponding circuit breaker. If the primary relay fails under exceptional conditions, the backup relay must trip within a specified time interval called CTI. Each primary-backup relay pair must adhere to a CTI ranging from 0.2 to 0.5 seconds. Additionally, each primary-secondary relay pair is required to maintain a CTI of 0.2 seconds.For the 22 identified primary-backup relay pairs, as demonstrated mathematically in equation (7), compliance with CTI requirements needs verification. Another critical constraint involves ensuring that each relay's operating time remains within specified limits. It is shown in equation (8) that all primary relays are expected to operate within the range of 0.05 to 1 second.

$$t_{bn} - t_{pn} >= 0.2;\ n = 1,2,3,\ldots,22 \quad (7)$$

$$0.05 < = t_n < = 1;\ n= 1,2,3,...,16 \quad (8)$$

t_{pn} and t_{bn} shows operating times of primary and backup relays of n^{th} pair. Here value of n is ranging from 1 to 22 identified relay pairs.

Once the optimal relay-settings have been found, the necessary constraints for each primary and backup relay pair need to be validated. In clusters that support more than one topology, optimised relay settings are defined for each topology, and in those circumstances, the optimal relay settings must fulfil CTI criteria for all topologies in the cluster. The CTI satisfaction verification for topology T-7 is displayed in Table 4. Table 4 demonstrates that the relay operation time stays within the specified bounds and that there is no CTI violation. The objective function value for cluster-1 is found to be 4.407822s.

3. Results and Discussion

The proposed method generates optimal relay settings for each of the fourteen network topologies, grouped into four clusters. Alongside ensuring compliance with CTI requirements, the relay settings specified for all clusters are validated for each topology within the same cluster. The minimum recorded CTI, as shown in Table 4, is 0.2510 seconds, which meets the minimum requirement of 0.2 seconds and applies to relays R6 through R16.Table

5 outlines the fitness function values for each of the four clusters. Cluster 1 exhibits the lowest fitness function value at 4.407822 seconds, while Cluster 4 has the highest at 5.683766161 seconds. The total objective function value for all four clusters combined is 19.41295 seconds.

4. CONCLUSION

The test network is protected using multiple setting group Directional Overcurrent Relays (DOCRs), a method that facilitates the determination of optimal relay settings while accounting for fluctuations in Renewable Energy (RE) outputs. Through the application of the K-means technique, 16 network topologies are categorized based on variations in RE generation and distributed into four distinct clusters. Optimal relay settings are then specified for each cluster. Verification of essential constraints, such as Coordination Time Interval (CTI) and relay operating time requirements, is conducted upon implementation of these relay configurations. One of the primary advantages of this approach is its elimination of the need for real-time relay setting computations, thereby reducing the risk of incorrect relay settings. Additionally, by transmitting only the serial number of previously stored settings via communication lines, the method minimizes data traffic on these lines.

Table 4 Constraint-Validation (Cluster-1) TOPOLOGY T7

Cluster 1										
Primary Relay					**Backup Relay**					**CTI**
R	**If**	**TMS**	**IP**	**Top**	**R**	**If**	**TMS**	**IP**	**Top**	
1	11076	0.0914	864.75	0.2447	**5**	1152	0.0533	681.65	0.7070	0.4624
1	11076	0.0914	864.75	0.2447	**14**	2465	0.0500	1383.6	0.6026	0.3579
2	2690	0.0542	172.61	0.1345	**4**	2690	0.0661	822.17	0.3856	0.2511
3	3540	0.0501	614.4	0.1967	**1**	3540	0.0914	864.75	0.4478	0.2511
4	7008	0.0661	822.17	0.2112	**16**	4889	0.1060	1096.6	0.4888	0.2776
4	7008	0.0661	822.17	0.2112	**7**	2071	0.0500	1119	0.5651	0.3539
5	3450	0.0533	681.65	0.2263	**3**	1265	0.0501	614.4	0.4820	0.2557
5	3450	0.0533	681.65	0.2263	**7**	2123	0.0500	1119	0.5431	0.3168
6	6194	0.0528	1338.3	0.2374	**16**	4895	0.1060	1096.6	0.4884	0.2510
6	6194	0.0528	1338.3	0.2374	**3**	1253	0.0501	614.4	0.4884	0.2511
7	4335	0.0500	1119	0.2550	**9**	4335	0.0812	1427.7	0.5060	0.2511
8	2613	0.0500	815.83	0.2973	**6**	2613	0.0528	1338.3	0.5483	0.2510
9	14803	0.0812	1427.7	0.2374	**11**	1914	0.0500	939.02	0.4884	0.2511
10	15065	0.1482	1540.9	0.4446	**8**	1346	0.0500	815.83	0.6957	0.2511
11	2757	0.0500	939.02	0.3218	**13**	2757	0.0500	1502	0.5729	0.2511
12	8554	0.0914	1375.8	0.3437	**10**	8554	0.1482	1540.9	0.5948	0.2511
13	4399	0.0500	1502	0.3223	**15**	4399	0.0731	1817	0.5733	0.2510
14	4276	0.0500	1383.6	0.3067	**12**	4276	0.0914	1375.8	0.5578	0.2511
15	9324	0.0731	1817	0.3076	**5**	1323	0.0533	681.65	0.5587	0.2511
15	9324	0.0731	1817	0.3076	**2**	339	0.0542	172.61	0.5587	0.2511

16	10518	0.1060	1096.6	0.3207	**14**	2542	0.0500	1383.6	0.5720	0.2513
16	10518	0.1060	1096.6	0.3207	**2**	264	0.0542	172.61	0.8897	0.5690

Table 5 Objective Function Value (All Clusters)

Cluster No	**Cluster-1**	**Cluster-2**	**Cluster-3**	**Cluster- 4**	**Total**
Obj-Function	4.407822	4.675862566	4.645502379	5.683766161	19.41295

References

[1] Tanrioven, M. Reliability and cost–benefits of adding alternate power sources to an independent micro-grid community. J. Power Sources **2005**, 150, 136–149.

[2] Senarathna, T.S.S.; Udayanga Hemapala, K.T.M. Department of Electrical Engineering, University of Moratuwa, Moratuwa, Sri Lanka Review of adaptive protection methods for microgrids. AIMS Energy **2019**, 7, 557–578.

[3] Maqbool, U.; Khan, U.A. Fault current analysis for grid-connected and Islanded Microgrid modes. In Proceedings of the 2017 13th International Conference on Emerging Technologies (ICET), Islamabad, Pakistan, 27–28 December 2017; IEEE: Piscataway, NJ, USA, 2018; pp. 1–5.

[4] Rockefeller, G.D.; Wagner, C.L.; Linders, J.R.; Hicks, K.L.; Rizy, D.T. Adaptive transmission relaying concepts for improved performance. IEEE Trans. Power Deliv. 1988, 3, 1446–1458.

[5] Prasai, A.; Du, Y.; Paquette, A.; Buck, E.; Harley, R.; Divan, D. Protection of meshed microgrids with communication overlay. In Proceedings of the 2010 IEEE Energy Conversion Congress and Exposition, Atlanta, GA, USA, 12–16 September 2010; IEEE: Piscataway, NJ, USA, 2011; pp. 64–71.

[6] T. S. S. Senarathna and K. T. M. U. Hemapala, “Optimized Adaptive Overcurrent Protection Using Hybridized Nature-Inspired Algorithm and Clustering in Microgrids,” Energies, vol. 13, no. 13, p. 3324, Jun. 2020, doi:10.3390/en13133324.

[7] M. Ojaghi and V. Mohammadi, "Use of Clustering to Reduce the Number of Different Setting Groups for Adaptive Coordination of Overcurrent Relays," in IEEE Transactions on Power Delivery, vol. 33, no. 3, pp. 1204-1212, June 2018, doi: 10.1109/TPWRD.2017.2749321

[8] T. K. Barik and V. A. Centeno, "K - Medoids Clustering of Setting Groups in Directional Overcurrent Relays for Distribution System Protection," 2020 IEEE Kansas Power and Energy Conference (KPEC), Manhattan, KS, USA, 2020, pp. 1-6, doi: 10.1109/KPEC47870.2020.9167531.

[9] S. D. Saldarriaga-Zuluaga, J. M. López-Lezama, and N. Muñoz-Galeano, “Optimal Coordination of Over-Current Relays in Microgrids Using Unsupervised Learning Techniques,” Applied Sciences, vol. 11, no. 3, p. 1241, Jan. 2021, doi: 10.3390/app11031241.

[10] S. D. Saldarriaga-Zuluaga, J. M. López-Lezama, and N. Muñoz-Galeano, “Optimal Coordination of Over-Current Relays in Microgrids Using Principal Component Analysis and K-Means,” Applied Sciences, vol. 11, no. 17, p. 7963, Aug. 2021, doi: 10.3390/app11177963.

[11] K. A. Saleh, H. H. Zeineldin, A. Al-Hinai and E. F. El-Saadany, "Optimal Coordination of Directional Overcurrent Relays Using a New Time–Current–Voltage Characteristic," in IEEE Transactions on Power Delivery, vol. 30, no. 2, pp. 537-544, April 2015, doi: 10.1109/TPWRD.2014.2341666.

[12] L. Hong, M. Rizwan, M. Wasif, S. Ahmad, M. Zaindin and M. Firdausi, "User-Defined Dual Setting Directional Overcurrent Relays with Hybrid Time Current-Voltage Characteristics-Based Protection Coordination for Active Distribution Network," in IEEE Access, vol. 9, pp. 62752-62769, 2021, doi: 10.1109/ACCESS.2021.3074426.

[13] M. Singh and A. Agrawal, "Cluster Based Protection Coordination using a New Voltage Current Time Inverse Relay," 2018 IEEE Power & Energy Society General Meeting (PESGM), Portland, OR, USA, 2018, pp. 1-5, doi: 10.1109/PESGM.2018.8586611.

[14] R. Tiwari, R. K. Singh and N. Kumar Choudhary, "Optimal Coordination of Dual Setting Directional Over Current Relays in Microgrid with Different Standard Relay Characteristics," 2020 IEEE 9th Power India International Conference (PIICON), Sonepat, India. 2020, pp. 1-6, doi: 10.1109/PIICON49524.2020.9112883.

[15] A. Chawla, B. R. Bhalja, B. K. Panigrahi, and M. Singh, “Gravitational Search Based Algorithm for Optimal Coordination of Directional Overcurrent Relays Using User Defined Characteristic,” Electric Power Components and Systems, vol. 46, no. 1, pp. 43–55, Jan. 2018, doi: 10.1080/15325008.2018.1431982.

[16] S. D. Saldarriaga-Zuluaga, J. M. López-Lezama, and N. Muñoz-Galeano, “Optimal Coordination of Overcurrent Relays in Microgrids Considering a Non-Standard Characteristic,” Energies, vol. 13, no. 4, p. 922, Feb. 2020, doi: 10.3390/en13040922

[17] P. Niranjan, N. K. Choudhary and R. K. Singh, "Performance Analysis of Different Optimization Techniques on Protection Coordination of Overcurrent Relay in Microgrid," 2019 International Conference on Electrical, Electronics and Computer Engineering (UPCON), Aligarh, India, 2019, pp. 1-6, doi: 10.1109/UPCON47278.2019.898009.

[18] T S S Senarathna, K T M Udayanga Hemapala, “Review of adaptive protection methods for microgrids” AIMS Energy, vol 7, no. 5, p. 557, Sep. 2019, doi: 10.3934/energy.2019.5.557.

[19] P Barra, D Coury, R Fernandes, “A survey on adaptive protection of microgrids and distribution systems with distributed generators”, Renewable and Sustainable Energy Reviews, vol 118, Feb. 2020, doi.org/10.1016/j.rser.2019.109524.

[20] A Samadi, R Mohammadi Chabanloo, “Adaptive coordination of overcurrent relays in active distribution networks based on independent change of relays’ setting groups”, International Journal of Electrical Power & Energy Systems, Vol 120, Sep. 2020, doi.org/10.1016/j.ijepes.2020.106026.

[21] A. S. Noghabi, J. Sadeh and H. R. Mashhadi, "Considering Different Network Topologies in Optimal Overcurrent Relay Coordination Using a Hybrid GA," in IEEE Transactions on Power Delivery, vol. 24, no. 4, pp. 1857-1863, Oct. 2009, doi: 10.1109/TPWRD.2009.2029057.

[22] M. Rojnić, R. Prenc, H. Bulat, and D. Franković, “A Comprehensive Assessment of Fundamental Overcurrent Relay Operation Optimization Function and Its Constraints,” Energies, vol. 15, no. 4, p. 1271, Feb. 2022, doi: 10.3390/en15041271.

[23] S. Mohammad, E. Ghadiri, K. Mazlumi, “Adaptive protection scheme for microgrids based on SOM clustering technique”, Applied Soft Computing, vol. 88, Mar 2020, doi.org/10.1016/j.asoc.2020.106062.

[24] H. Mohammadi, E. Fouladi, S. H. Hosseinian and G. B. Gharehpetian, "Dual Setting Directional Overcurrent Protection Coordination for Microgrids Considering Single Outage Contingency," 2020 28th Iranian Conference on Electrical Engineering (ICEE), Tabriz, Iran, 2020, pp. 1-6, doi: 10.1109/ICEE50131.2020.9260598.

[25] K. A. Saleh, H. H. Zeineldin and E. F. El-Saadany, "Optimal Protection Coordination for Microgrids Considering N-1 Contingency," in IEEE Transactions on Industrial Informatics, vol. 13, no. 5, pp. 2270-2278, Oct. 2017, doi: 10.1109/TII.2017.2682101.

[26] T. Khurshaid, A. Wadood, S. Gholami Farkoush, C. -H. Kim, J. Yu and S. -B. Rhee, "Improved Firefly Algorithm for the Optimal Coordination of Directional Overcurrent Relays," in IEEE Access, vol. 7, pp. 78503-78514, 2019, doi: 10.1109/ACCESS.2019.2922426.

[27] A. A. Balyith, H. M. Sharaf, M. Shaaban, E. F. El-Saadany and H. H. Zeineldin, "Non-Communication Based Time-Current-Voltage Dual Setting Directional Overcurrent Protection for Radial Distribution Systems With DG," in IEEE Access, vol. 8, pp. 190572-190581, 2020, doi: 10.1109/ACCESS.2020.3029818.

[28] H. K. Zand, K. Mazlumi and A. Bagheri, "Protection Coordination for Micro-Grids based on Multi-Objective Optimization Considering Simultaneous Uncertainty," 2019 International Conference on Protection and Automation of Power System (IPAPS), Iran, 2019, pp. 7-11, doi: 10.1109/IPAPS.2019.8641950.

[29] H. M. Bakr, M. F. Shaaban and A. H. Osman, "Impacts of Allocating Distributed Generation on Protection System," 2020 6th International Conference on Electric Power and Energy Conversion Systems (EPECS), Istanbul, Turkey, 2020, pp. 107-111, doi: 10.1109/EPECS48981.2020.9304950.

[30] University of Washington. Power Systems Test Case Archive; University of Washington: Seattle, WA, USA. Available online: http://labs.ece.uw.edu/pstca/pf14/pg_tca14bus.htm

[31] K. A. Saleh, H. H. Zeineldin and E. F. El-Saadany, "Optimal Protection Coordination for Microgrids Considering N-1 Contingency," in IEEE Transactions on Industrial Informatics, vol. 13, no. 5, pp. 2270-2278, Oct. 2017, doi: 10.1109/TII.2017.2682101.