Transactions on Machine Intelligence 8(4) (2025) 233–247

ISSN Online: 2821-1693

Transactions on Machine Intelligence

Journal Homepage: https://tmachineintelligence.ir/

Optimized Coordination of Overcurrent Relays in Microgrids Using the Grey Wolf Optimization Algorithm

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ARTICLE INFO

Article History:
Received 3 September 2025
Received in revised form 10 November 2025
Accepted 2 December 2025
Available online 23 December 2025

Keywords:
Microgrid, Microgrid Protection, Overcurrent Relay Coordination, Grey Wolf Optimization (GWO) Algorithm, Metaheuristic Optimization, IEEE 30-Bus System

ABSTRACT

This study focuses on investigating protection challenges in microgrids and presenting a novel approach for the optimal coordination of overcurrent relays using the Grey Wolf Optimization (GWO) algorithm. Due to the presence of distributed generation (DG) sources and the capability of operating in both grid-connected and islanded modes, microgrids experience variations in short-circuit levels and bidirectional power and fault-current flows, which can adversely affect the proper operation of conventional protection relays. To address this issue, the coordination problem between primary and backup relays is formulated as an optimization problem, and the GWO algorithm, inspired by the hierarchical structure and cooperative hunting behavior of grey wolves, is employed to determine the optimal values of the relay pickup current setting (ISET) and time multiplier setting (TMS). The test system considered in this study is the standard IEEE 30-bus system. Simulation results demonstrate that the proposed method significantly reduces relay operating times, prevents interference between primary and backup relay operations, and maintains proper protection coordination under various operating conditions. A comparison with other metaheuristic algorithms, including the Genetic Algorithm (GA) and Particle Swarm Optimization (PSO), indicates that the GWO algorithm provides faster convergence, greater stability, and more accurate solutions. Overall, the findings demonstrate the high effectiveness of the GWO algorithm in enhancing the reliability and improving the protection performance of microgrids. Therefore, it can be considered an effective approach for the design and operation of future microgrid protection systems. Future studies are recommended to investigate hybrid approaches combining GWO with other swarm intelligence techniques and to evaluate its performance in larger microgrids under load and distributed-generation uncertainties.

1. INTRODUCTION

In recent years, the continuous growth in electricity demand, the depletion of fossil-fuel resources, environmental concerns associated with greenhouse-gas emissions, and the need to move toward sustainable development have driven the global power industry toward fundamental changes in the structure of power generation and distribution. One of the emerging concepts in this context is the microgrid, which is defined as a small-scale local network

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http://dx.doi.org/10.22034/tmi.2025.253006

comprising distributed generation (DG) sources, energy storage systems, electrical loads, and an intelligent management and control system. Microgrids are capable of operating in both grid-connected and islanded modes. In the event of a fault or disturbance in the main grid, they can continue operating independently and supply electricity to critical loads. This capability has established microgrids as one of the key solutions for enhancing reliability, improving power quality, reducing power losses, and increasing energy efficiency in modern distribution networks.

On the other hand, the integration of distributed generation sources with different characteristics, such as wind turbines, photovoltaic (PV) systems, microturbines, and combined heat and power (CHP) systems, means that microgrids, in addition to serving electrical loads, exhibit bidirectional power flows and more complex dynamics than conventional networks. This fundamental change in power and current flow patterns poses significant challenges to the conventional protection philosophy used in distribution systems, as traditional protection relays are primarily designed based on unidirectional fault currents and relatively fixed short-circuit levels. In microgrids, changes in fault-current direction, variations in short-circuit levels between grid-connected and islanded operating modes, and the presence of power-electronic interfaces complicate fault detection and may, in many cases, result in incorrect or ineffective operation of overcurrent relays. Therefore, the development of advanced protection schemes and the optimization of relay settings in microgrids have emerged as important research topics in the field of power systems.

A review of previous studies indicates that researchers have proposed various approaches to address these challenges. Some studies have focused on the use of digital relays and intelligent protection modules capable of rapidly detecting faults and isolating the faulty section through communication channels and centralized control systems. Other studies have proposed protection approaches based on differential protection, impedance-based protection, and adaptive protection to account for structural changes in microgrids. In addition, the application of metaheuristic and swarm-intelligence algorithms for the optimal coordination of overcurrent relays has received considerable attention in recent years. Methods such as the Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), and other metaheuristic techniques have been employed to solve the nonlinear and complex relay coordination problem. Although these methods have produced valuable results, they are often subject to limitations, including entrapment in local optima, the need for multiple tuning parameters, and relatively long convergence times. In this context, the Grey Wolf Optimization (GWO) algorithm, introduced in 2014, has attracted considerable attention because of its simple structure, strong global search capability, suitable convergence characteristics, and relatively low number of control parameters. Inspired by the social hierarchy and cooperative hunting behavior of grey wolves, GWO has demonstrated its effectiveness in a wide range of engineering optimization problems, particularly in power-system applications.

The motivation for employing GWO in the coordination of overcurrent relays in microgrids arises from the high complexity of optimizing the relay pickup current setting (ISET) and time multiplier setting (TMS) in the presence of distributed generation. The multiple constraints and nonlinear characteristics of this optimization problem make it computationally challenging. The relays must be coordinated such that their operating times are minimized while avoiding interference between primary and backup relay operations and maintaining the required protection coordination under all relevant microgrid operating conditions. With its capability to explore a broad search space and dynamically update candidate solutions, the GWO algorithm can effectively determine near-optimal relay parameters and improve the overall protection performance of the network. Furthermore, the use of standard benchmark systems, such as the IEEE 30-bus test system, provides additional credibility to the study and facilitates meaningful comparisons with the results of another research. Simulation results demonstrate that the application of GWO can lead to a significant reduction in relay operating times, improved protection coordination, and enhanced network reliability.

Overall, the present study focuses on the application of the Grey Wolf Optimization algorithm to the coordination of overcurrent relays in microgrids and seeks to address an existing gap in the research literature. Many previous studies have either relied exclusively on conventional methods or employed traditional metaheuristic algorithms that are subject to specific limitations. In contrast, the proposed approach based on GWO aims to achieve more accurate, stable, and practically applicable solutions. Accordingly, the primary contribution of this study lies in introducing and evaluating an efficient optimization-based approach for microgrid protection, with the potential for further development and extension to larger and practical power networks. Thus, the present research is significant not only from a scientific and theoretical perspective but also from a practical standpoint, as it can provide effective solutions for the power industry and operators of modern distribution networks.

2. LITERATURE REVIEW

Over the past two decades, the research literature on microgrid protection, particularly the optimal coordination of directional overcurrent relays (DOCRs), has grown considerably. The primary reasons for this development are the significant variations in short-circuit levels and fault-current directions under grid-connected and islanded operating conditions, as well as the widespread integration of distributed generation (DG) and power-electronic interfaces. These factors invalidate many of the assumptions underlying conventional relay design and highlight the need for adaptive protection strategies and advanced optimization techniques [1], [2]. Recent comprehensive reviews of microgrid protection and the development of relay coordination schemes indicate that conventional approaches based on inverse definite minimum time (IDMT) characteristics and fixed selectivity margins are insufficient when dealing with dynamic topologies, changes in operating configurations, and variations in fault currents. Therefore, these approaches need to be complemented by intelligent and metaheuristic techniques, as well as by exploiting nonconventional relay characteristics [3], [4].

Within this context, a strong research direction has emerged around the optimization of time multiplier setting (TMS) and pickup current setting (Iset), employing a variety of techniques, including linear/nonlinear programming, genetic algorithms, particle swarm optimization, imperialist competitive algorithm, ant colony optimization, artificial bee colony algorithms, and, more recently, advanced approaches such as Electromagnetic Field Optimization Algorithm (EMPA), Time-Varying Acceleration Coefficient Particle Swarm Optimization (TVAC-PSO), and Grey Wolf Optimization (GWO) [5]–[11]. Pioneering studies based on GA and hybrid GA-NLP approaches demonstrated that the constrained and rugged relay coordination problem could be solved by defining an objective function based on the total operating time of primary relays subject to coordination time interval (CTI) constraints. However, challenges such as entrapment in local optima and sensitivity to algorithmic parameters remained [8].

This line of research was further developed through enhanced versions of PSO, such as TVAC-PSO, which demonstrated shorter convergence times and improved solution quality across several benchmark systems, thereby confirming its effectiveness in the simultaneous coordination of multiple relays [6], [7], [10]. Another research direction has focused on incorporating nonconventional relay characteristics, including treating the upper limit of the plug setting multiplier (PSM) as a decision variable and allowing the selection of different operating curves. Such approaches increase the flexibility of protection coordination schemes and provide better compatibility with practical field conditions [9], [12].

At the microgrid level, recent literature clearly emphasizes the multi-scenario nature of the coordination problem. These studies demonstrate that selectivity constraints and objective functions must remain valid under worst-case operating scenarios, including both grid-connected and islanded modes. Approaches such as clustering operating scenarios and subsequently solving the coordination problem for each cluster using metaheuristic algorithms including GA, PSO, Invasive Weed Optimization (IWO), and Artificial Bee Colony (ABC) have been developed precisely for this purpose [13].

In parallel, review studies published during 2023–2025 have provided a more recent perspective on existing research gaps. These studies highlight the need for adaptive and self-adaptive protection schemes, the integration of machine learning with metaheuristic optimization, the incorporation of multi-objective constraints involving reliability, voltage stability, and SEL/SAIDI indices, and fair comparison of optimization algorithms using common benchmark systems [1], [3], [4]. Moreover, numerous application-oriented studies conducted on standard 3-, 8-, 9-, 15-, and 30-bus systems, as well as benchmark IEC microgrids, have demonstrated that the appropriate selection of the objective function such as minimizing the total operating time, minimizing the aggregate penalty associated with CTI violations, or employing a multi-objective formulation and the proper design of constraint penalties involving CTI, Iset/TMS limits, and directional characteristics play a decisive role in the success of relay coordination algorithms [10]–[12].

In this context, GWO has emerged as a metaheuristic algorithm characterized by a small number of tuning parameters and a favorable balance between exploration and exploitation. It has been applied to DOCR coordination either independently or through enhanced variants, such as Enhanced Grey Wolf Optimization (EGWO), as well as in hybrid combinations with other optimization algorithms. Reported results indicate significant reductions in the objective function, improved preservation of CTI under multiple operating scenarios, and greater convergence stability compared with conventional approaches [14], [15].

Furthermore, recent studies on the joint coordination of overcurrent and distance relays, as well as adaptive protection schemes capable of accounting for fault-location changes and fluctuations in short-circuit current, indicate that integrating inter-relay constraints and performing joint optimization, although it increases the complexity and nonlinearity of the problem, is essential from a system-security perspective [7], [16]. A recent IET-GTD review published in 2024, which summarizes algorithmic advances in this field, emphasizes the development of robust coordination schemes capable of accommodating load/generation variations and evolving microgrid topologies. It also identifies future research directions, including the use of nonclassical relay characteristics, integration of reinforcement learning, and development of industry-oriented multi-objective performance criteria [4].

From a methodological perspective, recent approaches for reducing computational requirements include operating-scenario clustering, engineering-rule-based preconditioning of search-space boundaries, and the use of worst-case objective functions across multiple scenarios. These strategies are intended to ensure that the resulting coordination scheme remains valid under both islanded and grid-connected operating conditions [12], [13]. In addition, some studies have shown that introducing new decision variables, such as the selection of the standard operating curve, alongside TMS and PSM, can improve the flexibility and quality of the obtained solution. However, this also enlarges the search space and consequently necessitates more efficient optimization methods, such as enhanced PSO/GWO variants or hybrid algorithms [6], [9], [15].

Overall, the literature indicates that: (1) relay coordination in microgrids is inherently multi-scenario, constrained, and nonconvex; (2) modern metaheuristic algorithms, including enhanced PSO, EMPA, JAYA, GWO, and hybrid variants, generally outperform conventional methods in obtaining more stable solutions with shorter operating times; (3) incorporating nonconventional relay characteristics, such as PSM limits, operating-curve selection, directional constraints, and dynamic CTI, can address important performance gaps associated with classical approaches; (4) combining machine-learning techniques, including scenario clustering and reinforcement learning, with metaheuristic algorithms can provide solutions that are more adaptable to microgrid variability; and (5) future research should focus on fair benchmarking of algorithms using common benchmark systems, incorporating uncertainties associated with renewable generation and load demand, and conducting laboratory- and field-level implementations to facilitate the transition from simulation-based studies to industrial applications [7], [16].

3. METHODOLOGY

The methodology adopted in this study is based on the design and implementation of an optimization framework for the coordination of overcurrent relays in microgrids using the Grey Wolf Optimization (GWO) algorithm. GWO is a nature-inspired optimization algorithm based on the social behavior of grey wolves. By simplifying the hierarchical relationships among alpha, beta, delta, and omega wolves, the algorithm mathematically models the processes of searching for and hunting prey. Owing to its simple structure, limited number of tuning parameters, and strong search capability in complex solution spaces, GWO is well suited to solving nonlinear and constrained problems such as relay coordination in modern microgrids.

In this study, the overcurrent relay coordination problem is first formulated as a mathematical optimization problem in which the decision variables consist of the relay pickup current setting (Iset) and time multiplier setting (TMS). The objective function is defined to minimize the total operating time of the primary relays under fault conditions while ensuring that the coordination constraints between primary and backup relays are satisfied under all relevant operating scenarios, including grid-connected and islanded modes. The relay operating time is calculated using the standard inverse definite minimum time (IDMT) characteristic, which is determined as a function of the fault current flowing through the relay and the selected Iset and TMS values.

The selectivity constraints are then formulated such that, for each fault location and under both islanded and grid-connected conditions, the difference between the operating times of the backup and primary relays is at least equal to a specified coordination time interval (CTI). In this study, the CTI is set to 0.2 s. In addition, permissible ranges for Iset and TMS are imposed according to the technical specifications of the relays and the protection policies of the system operator, ensuring that the obtained solutions are also practically feasible.

The GWO algorithm is subsequently employed to solve the formulated optimization problem. In this algorithm, the hierarchical positions of the wolves are modeled such that the best current solution is designated as the alpha wolf, while the second- and third-best solutions are assigned to the beta and delta wolves, respectively. The remaining solutions are considered omega wolves. The search process is guided by these leading solutions. The position-updating mechanism in GWO is based on three principal stages: prey tracking, prey encircling, and prey attacking, which are mathematically modeled using vector relationships and the stochastic coefficients A and C.

In the proposed framework, each candidate solution, represented by a wolf in the population, corresponds to a vector containing the Iset and TMS values of all relays. The quality of each candidate solution is evaluated by calculating the objective-function value while checking the imposed constraints. An initial population of candidate solutions is first generated randomly within the permissible parameter ranges, and the operating time of each relay is calculated for all fault scenarios. Based on the objective-function values, the three best candidate solutions are selected as the alpha, beta, and delta wolves. The remaining wolves update their positions according to a combination of the positions of the alpha, beta, and delta wolves and corresponding weighting coefficients.

This process is repeated at each iteration, progressively directing the population toward the region of the search space that provides the best relay coordination. To ensure compliance with the imposed constraints, a penalty-function approach is employed. Accordingly, any violation of the coordination constraints, particularly CTI requirements or the permissible Iset and TMS ranges, increases the objective-function value and consequently reduces the probability of the corresponding solution being selected as a superior candidate.

In the simulations, the standard IEEE 30-bus system is employed as the test platform. The system includes distributed generation sources, loads, and multiple transmission/distribution lines and, in terms of its structural characteristics, provides a suitable benchmark for evaluating microgrid protection strategies. Three-phase faults are applied at different locations, and the currents flowing through the relays are calculated under both grid-connected and islanded operating conditions. The GWO algorithm then determines the optimal Iset and TMS values based on these fault-current values and the relay coordination constraints.

The algorithmic parameters, including population size, maximum number of iterations, and the ranges of coefficients A and C, are empirically selected to establish an appropriate balance between local exploitation and global exploration. In this study, a population size of 30, a maximum of 200 iterations, and coefficient values within the range [0, 2] are considered. The optimization process continues until either the maximum number of iterations is reached or no further improvement in the objective-function value is observed.

Following execution of the algorithm, the optimal relay settings are extracted, and the network performance under fault conditions is evaluated. The results indicate that GWO successfully reduces the operating times of the primary relays, maintains coordination between primary and backup relays under all considered scenarios, and provides superior performance compared with the initial settings or conventional coordination approaches. Furthermore, the convergence curve demonstrates that the candidate population rapidly approaches the optimal region and that the algorithm is capable of avoiding entrapment in local optima. Overall, the proposed GWO-based methodology provides a comprehensive framework for overcurrent relay coordination in microgrids, offering favorable performance in terms of both solution accuracy and convergence speed, with potential applicability to larger networks and more complex operating conditions.

4. SIMULATION

Protection against faults is one of the essential requirements in the design of a distribution system. An effective protection scheme should be capable of isolating only a small portion of the system when a fault occurs, thereby preventing other parts of the network from being affected and avoiding the unnecessary operation of protection devices unrelated to the fault. In such a protection scheme, each protection device should perform its primary function as quickly as possible. However, when a fault occurs in the system, the faulty section must also be protected by another device acting as a backup protection.

Before applying the GWO algorithm to the coordination of overcurrent relays, a set of preliminary data for the test network is required. These data include identification of the primary and backup relay pairs, as well as determination of the normal load currents and short-circuit currents associated with the relays. The relay settings must be selected such that the operating times are minimized, every section of the system is protected by both a primary and a backup relay, and no undesirable interference occurs between the operations of the primary and backup relays. Therefore, the overcurrent relay coordination problem can be formulated as a highly constrained optimization problem. When optimization techniques are employed to solve the optimal coordination problem, an appropriate objective function that represents the desired characteristics of the protection system must first be defined. The constraints governing the optimization variables are then specified, and the optimization problem is solved by minimizing the objective function. Depending on the characteristics of the problem, different optimization techniques can subsequently be employed to obtain an appropriate solution.

In power systems, when a fault occurs, it should be detected by the nearest relay, referred to as the primary relay, which then issues a trip command to the associated circuit breakers to clear the fault. If the primary relay or its associated circuit breaker fails to operate for any reason, the fault must be cleared by the backup relay through the operation of breakers associated with adjacent network elements. Therefore, to calculate the operating times of the relays, a backup relay must be identified for each primary relay; in other words, the corresponding primary–backup relay pairs must be determined.

For this purpose, load-flow analysis is required for overcurrent relay coordination. In this study, the Newton–Raphson method is employed for load-flow calculations. The characteristic equation of an overcurrent relay expresses its operating time as a function of the relay pickup setting and time-setting coefficient. The objective of coordinating directional overcurrent relays (DOCRs) is to determine the optimal current and time settings for all relays. Therefore, establishing the relationship between fault current and relay operating time constitutes one of the most important components of the modeling process in this study. In the present research, the GWO algorithm is employed as an efficient optimization technique. Figure 1 illustrates the implementation procedure of the algorithm for the optimal coordination of overcurrent relays.

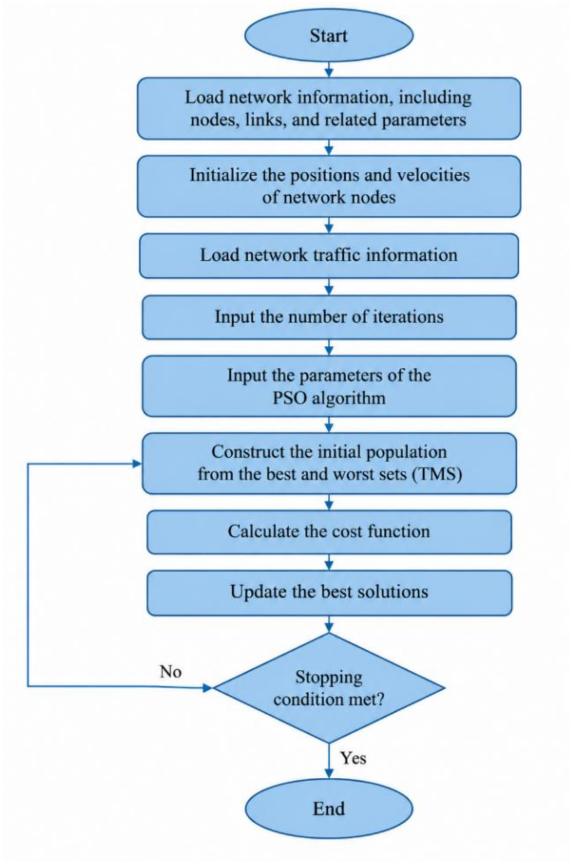

Fig. 1. Proposed Flowchart

Distribution systems are usually operated radially, and overcurrent relays and fuses are used for the protection of radial systems. Since the direction of the fault current is unidirectional, the complexity of the protection system is greatly reduced.

With the presence and increase of distributed generation (DG) units in distribution systems, the complexity of protective relay coordination has increased. In the presence of DGs, the magnitude of line currents and the direction of power flow will change; therefore, the existing protective system will no longer be able to maintain its previous coordination capability.

4.1. Formulation of the Protective Coordination Problem

The operating time of an overcurrent relay is a function of the short-circuit current passing through it. This function is described by two parameters: TDS (Time Dial Setting) and Ip (pickup current). The function commonly used for inverse-time relays is given by Equation (1):

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

The constants $A$and $B$are selected according to the type of relay. In this project, the IDMT (Inverse Definite Minimum Time) model is used, in which the constants $A$and $B$are equal to 0.14 and 0.02, respectively.

The objective of the problem is to minimize the operating time of all relays that are exposed to the fault. As mentioned in the previous section, two operating structures (grid-connected and islanded) are considered in this problem. The objective function of the problem is the sum of the operating times of the relays, which must be minimized, and is expressed as Equation (2):

$$OF = \sum_i t_i$$
$$Minimize\ T = F_{NN}(T_p, i) \quad (2)$$

where t_i is the operating time of the i-th relay

F_{NN}: $neural\ network\ function$
T_p: operating time of the fuse
I: location of the fuse

In addition, a time interval must be established between the primary and backup relays, which is known as the Coordination Time Interval (CTI). In this paper, the CTI is considered equal to 0.2 seconds. As will be discussed in the following sections, there may be more than one backup relay for each fault location; therefore, some relays must satisfy several CTI constraints for a single fault. The set of constraints mentioned in the problem is according to Equation (3):

$$t_{\text{backup}} - t_{\text{primary}} \geq \text{CTI} \quad (3)$$

The allowable ranges of TDS (Time Dial Setting) and I_p(pickup current) must be specified. These ranges are usually determined empirically. TDS can take the discrete values specified by the relay manufacturer; however, for simplicity, this discrete constraint is not considered here. The value of I_p is selected with a margin larger than the load current and smaller than the minimum short-circuit current. Therefore, the relays must satisfy constraints (4) and (5):

$$0.1 \leq \text{TDS} \leq 1.1 \quad (4)$$

$$I_{\text{load}} < I_p < I_{\text{sc,min}} \quad (5)$$

4.2. Constraint Handling Technique

Evolutionary algorithms do not have a specific method for implementing constraints; constraints are usually incorporated into the objective function. There are various methods for constraint handling. In this project, the Static Penalty method has been used. In this method, constraint violations are applied as a penalty to the objective function. The penalty is proportional to the amount of violation and affects the objective function with an appropriate sign.

For example, if the optimization problem is in the form of Equation (5):

$$\begin{array}{ll} \text{Minimize} & f(x) \\ \text{Subject to} & g_i(x) \leq 0, i = 1,2, \dots, m \end{array} \quad (5)$$

Since this is an optimization problem, the amount of violation must be calculated, and the problem can be expressed as Equation (6):

$$F(x) = f(x) + \sum_{i=1}^{m} \lambda_i \cdot \max(0, g_i(x)) \quad (6)$$

where λ_i are the penalty coefficients.

5. RESULTS AND ANALYSIS

In this section, the simulation results obtained in MATLAB software are presented. Load flow is performed to determine the line currents, and the settings are adjusted to prevent relay operation under load current conditions. In order to evaluate the proposed algorithm, a simulation was carried out on the 30-bus network.

5.1. IEEE 30-Bus Network

Since our objective is to study the distribution level, only the distribution sections are examined. The distribution part of the 30-bus network consists of 16 buses, 20 lines, and 39 overcurrent relays that are responsible for protecting the network. This distribution section of the 30-bus network is formed from buses 1, 6, and 13.

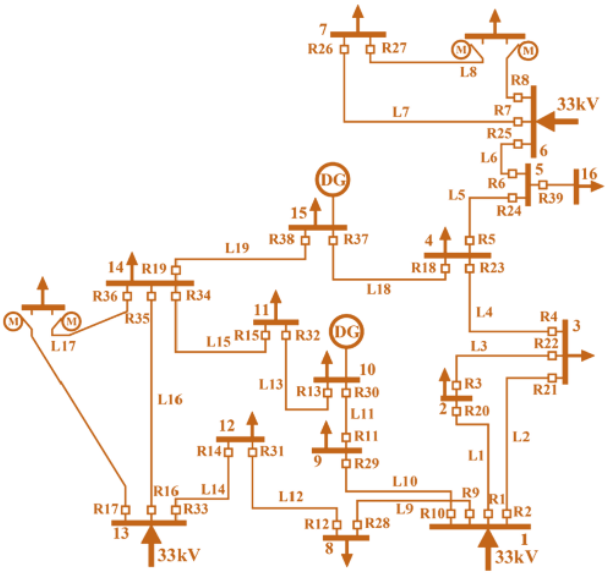

Fig. 2. IEEE 30-Bus Network

The values of the Time Multiplier Setting (TMS) as well as I_p have been considered as continuous variables. The information of the primary-backup relay pairs of the 30-bus network is presented. The parameters have been examined in two modes: islanded and grid-connected.

5.2. IEEE 30-Bus Network

The primary and backup relay pairs are shown in Table 1:

Table 1. Primary and Backup Relay Pairs in the 30-Bus Network

Backup Relay Number	Primary Relay Number	Backup Relay Number	Primary Relay Number
3-23	21	21-28-29	1
2-23	22	28-29	2
24-37	23	1	3
25	24	2-3	4
-	25	4-37	5
8	26	5	6
7	27	6	7
31	28	6	8
30	29	21-29	9
32	30	21-28	10
33	31	10	11
34	32	9	12
35-36	33	11	13
16-17-38	34	12	14

15-17-38	35	13	15
15-16-38	36	14-36	16
19	37	14-35	17
18	38	4-24	18
5-25	39	15-16-17	19
-	-	22	20

5.3. IEEE 30-Bus Network – Islanded Mode

In the islanded mode, load flow was performed for the 30-bus network, and the network characteristics are shown in the following table:

Table 2. Characteristics of the 30-Bus Network in Islanded Mode

Current through relay for fault F1 (A)	**Primary Relay Number**	**Current through relay for fault F1 (A)**	**Primary Relay Number**
2701	21	4079	1
2144	22	4096	2
1732	23	2407	3
3515	24	3177	4
1485	25	2769	5
759	26	1514	6
1108	27	2956	7
1050	28	3021	8
1104	29	3819	9
1359	30	4012	10
1917	31	2325	11
1843	32	2891	12
3427	33	1965	13
3130	34	1708	14
1906	35	1431	15
3302	36	3515	16
1888	37	3963	17
1393	38	2618	18
2942	39	3115	19
-	-	1675	20

Note: The table shows the fault current (for fault F1) passing through each primary relay in the islanded operating mode of the IEEE 30-bus distribution network.

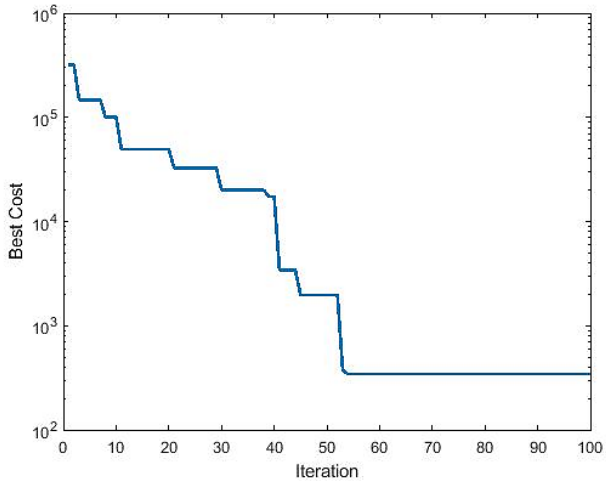

Fig. 3. Optimization using Differential Evolution algorithm for the IEEE 30-bus network in islanded mode

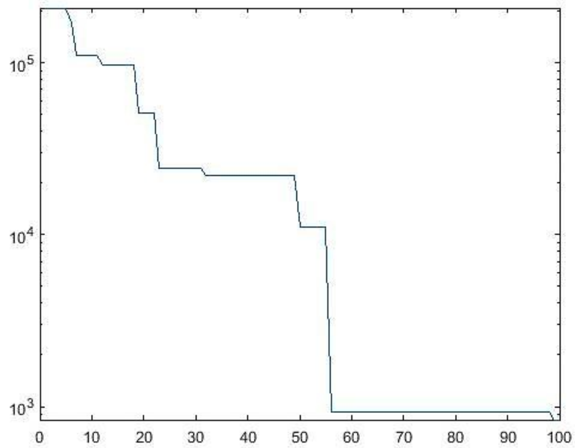

Fig. 4. Optimization using Harmony Search algorithm for the IEEE 30-bus network in islanded mode

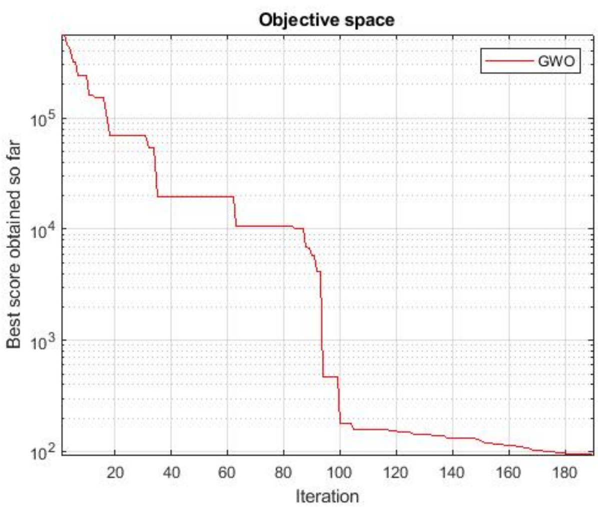

Fig. 5. Optimization using GWO (Grey Wolf Optimizer) algorithm for the IEEE 30-bus network in islanded mode

Table 3. Results obtained by the proposed algorithm for the IEEE 30-bus network using PSO and GWO algorithms

TMS (PSO)	I_{pickup}(kA) (PSO)	TMS (GWO)	I_{pickup}(kA) (GWO)	Relay Number
0.1231	0.5604	0.1008	0.3309	1
0.1549	0.2435	0.1029	0.1823	2
0.1234	0.4356	0.1117	0.2460	3
0.1212	0.2145	0.1039	0.1273	4
0.1101	0.5432	0.1009	0.1507	5
0.1231	0.1346	0.1000	0.2358	6
0.0987	0.1456	0.1081	0.1615	7
0.1652	0.1224	0.1012	0.0620	8
0.1431	0.0456	0.1001	0.0433	9
0.1321	0.2755	0.1000	0.3624	10
0.1098	0.3415	0.1000	0.3415	11
0.1321	2.1424	0.1022	2.7263	12
0.1098	0.2634	0.1062	0.1358	13
0.0987	0.1273	0.1000	0.2777	14
0.0980	0.2341	0.1000	0.1981	15
0.1123	0.1624	0.1081	0.0918	16
0.2312	0.8360	0.1000	0.8790	17
0.2154	0.7368	0.1000	0.6739	18
0.1098	0.8363	0.1006	0.4576	19
0.1087	0.2534	0.1134	0.1106	20
0.1231	0.2132	0.1038	0.1171	21
0.1612	0.8254	0.1050	0.6208	22
0.1231	0.1524	0.1012	0.0567	23
0.1076	0.8976	0.1103	0.3079	24
0.1239	0.1876	0.1197	0.0471	25
0.1430	0.9876	0.1000	0.1440	26
0.1321	2.0987	0.1000	0.0501	27
0.1383	0.8765	0.1133	0.0242	28
0.1009	0.1328	0.1014	0.0746	29
0.1432	1.7650	0.1075	0.0165	30
0.1098	0.1547	0.1000	0.0261	31
0.1142	1.0987	0.1042	1.1724	32
0.1205	0.0875	0.1045	0.0375	33
0.1321	0.0164	0.1009	0.2881	34
0.1870	0.5432	0.1000	0.0363	35
0.1121	0.1131	0.1079	0.0754	36
0.1123	0.9876	0.1004	2.4678	37
0.1211	0.1837	0.1015	0.1594	38
0.1080	0.3452	0.1000	0.2959	39

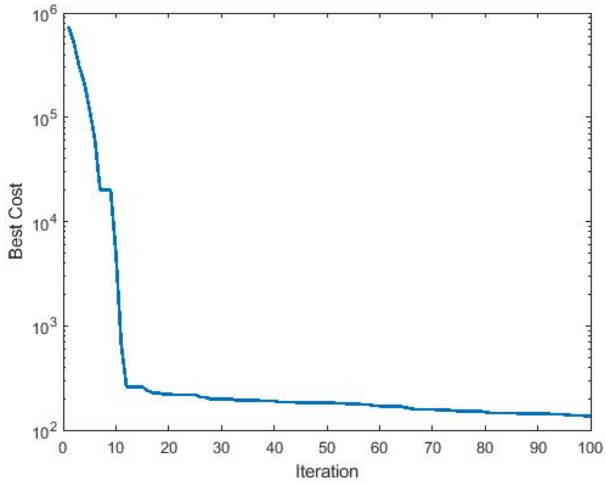

Fig. 6. Optimization using PSO (Particle Swarm Optimization) algorithm for the IEEE 30-bus network in islanded mode

In this paper, the problem of overcurrent relay coordination in distribution networks has been modeled and solved using the GWO algorithm. Furthermore, the values of TMS and I_{set}, as well as different characteristics for the overcurrent relays, have been obtained. In this paper, the capability of selecting different characteristics of overcurrent relays has been used in solving the coordination problem within the optimization process, and the best characteristic has been selected for each overcurrent relay. Using the GWO optimization method, the TMS and I_{set}settings for the 30-bus networks have been calculated for two scenarios: islanded and grid-connected.

6. CONCLUSION

In order to validate the model, various scenarios need to be performed on the 30-bus network. In this paper, the islanded and grid-connected scenarios are examined. The simulation was carried out in the MATLAB environment, and the proposed algorithm is used. Since the proposed algorithm uses load-flow calculations in each iteration, it has the ability to model the application of loads or distributed generation resources as well as connection to the grid. Connection to the infinite bus at the relevant buses is considered, and the proposed algorithm is applied. The proposed algorithm must perform the calculations online alongside the network, and in the event of any change in the network configuration, based on the network parameter calculations in each iteration of the algorithm, it can easily perform new calculations according to the network changes. In other words, it is robust against network changes.

Declaration

We acknowledge that we used ChatGPT to enhance the academic writing of our manuscript while ensuring the originality and integrity of our work.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

Acknowledgments

We would like to express our gratitude to all individuals who contributed to this project.

Declaration of Interest

The authors declare that they have no competing interests.

Funding

This research received no specific grant from any funding agency, commercial, or not-for-profit sectors.

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