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Research Article

Application of the JAYA Algorithm in Solving the Problem of the Optimal Coordination of Overcurrent Relays in Single- and Multi-Loop Distribution Systems

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To ensure a safe and trustworthy pattern in contradiction to the possible faults, a precise, reliable, and fast relaying strategy is of high importance in an electrical power system. These challenges give the impression of being more refined in multi-loop distribution systems. More recently, overcurrent relays (OCRs) have evolved as proficient counteragents for such cases. In this way, inaugurating an optimal protection coordination strategy is accepted as the primary precondition in guaranteeing the safe protection of the coordination strategy. This study is aimed at lessening the overall operational time of the main relays in order to reduce the power outages. The coordination problem is conducted by adjusting only one parameter, namely the time multiplier setting (*TMS*). In electrical power relaying coordination, the objective function to be minimized is the sum of the overall operational time of the main relays. In the prescribed work, the coordination of the OCRs in the single- and multi-loop distribution network is realized as an optimization issue. The optimization is accomplished by means of JAYA algorithm. The suggested technique depends on the idea that the result acquired for a certain issue ought to pass near the finest result and avert the worst result. This technique involves only the common control factors and does not involve specific control factors. JAYA is adopted to OCR problem and run 20 times with the same initial condition for each case study, and it has been realized that for every run, the JAYA algorithm converges to the global optimum values requiring less number of iterations and computational time. The results obtained from JAYA algorithm are compared with other evolutionary and up-to-date algorithms, and it was determined that JAYA outperforms the other techniques.

1. Introduction

Power systems are growing day by day, which has created some unwanted security problems and threat issues related to the reliability and stability of the systems under a threat condition. Such issues are highly important for power system engineers [1–3]. To keep the system in a reliable condition and to ensure that there is continuous power without any interruption to industries, telecommunication networks, and at the consumer level, there is a need for a fast, stable, and reliable system that can handle such a problem in a quick manner without any delay. In a power system, the protection system is one of the counteragents that detects and clears a fault as soon as possible [4, 5]. The protection system is a combination of different overcurrent relays (OCRs) and circuit breakers. These protection relays sense the faulty portion in the system and isolate it in order to guarantee that the system excludes the least amount of the strong portion of the system in real time. In a protection system, the applicable strategy of relays is necessary to keep the proper operation of the overall protection system smooth. The key objectives of the coordination problem are to guarantee that the relays do not work out of the circle, to hide the unimportant disconnectivity of the robust portion, and to evade maloperation of the relays. The faulty portion in a power system is promptly disengaged with the help of circuit breakers by these relays once it satisfies the necessities of selectivity, sensitivity, and reliability that makes the coordination important for these relays [6]. The OCRs are a useful choice in a technical and economic sense for the industrial area in view of the primary protection in a sub-transmission system and backup protection in a transmission system [7, 8]. The goal of optimal coordination issue is to sort out the minimal relay setting, which is subject to relay characteristic graphs, constraints, and the restriction of the relay settings [9]. The optimization theory dealing with finding the optimal relay coordination performs a vital part in power network [10]. Recently, scholars and researchers have used different types of optimization methodologies are not only limited to OCR coordination problem but also have significant application in different fields [11–13]. In [14], whale optimization algorithms were introduced to relay coordination problem. In [15], a firefly algorithm (FA) was used to analyse directional overcurrent relay (DOCR). In [16], grey wolf optimization was used to interrogate the relay problem. In [17–22], various styles of particle swarm optimization were interrogated to deal with the relay coordination issue. In [23–26], a different version of a genetic algorithm to enhance the convergence characteristics of the genetic algorithm was applied. In [27, 28], root tree algorithms were introduced to relay coordination problem. In [29], the CFA was proposed to assess the coordination issues. In [30], a hybrid symbiotic organism optimizer was proposed to resolve OCR issue. In [31], comparative study was done using different metaheuristic algorithms. In [32], the DOCR is formulated as mixed-integer nonlinear problem and was solved using hybrid whale optimization.

The drawback of the previous optimization techniques, as well as the metaheuristic, and evolutionary optimizations is the possibility of merging to standards that may not be optimal but instead are trapped at a local optimal value. To comprehend this problem, a JAYA algorithm strategy is inspected in this investigation to determine the precise and optimal OCR coordination and is related to other up-to-date algorithms.

This paper proposes the JAYA algorithm for finding the optimal coordination of OCR. To confirm the efficiency of the suggested JAYA algorithm, it is related to other methods of factors identification problems for different OCR models. The simulation results and analyses validate that JAYA shows a greater performance in terms of its precision and consistency. The efficiency of JAYA is validated through inclusive simulations and evaluations on parameters identification problems of various multi-loop distribution systems. Thus, JAYA can be an actual substitute for other complex optimization issues of higher and more complicated bus systems.

2. Formulation of OCR Problem

The relay coordination in a single- and multi-loop system is explained as an optimization issue. The objective function related to this problem is as follows:

$$\min f = \sum_{j=1}^{n} w_j T_{j,k}, \tag{1}$$

where the parameters w_j and $T_{j,k}$ are the weight and operational time of the relay, respectively. For every relay, $w_j = 1$ [33, 34]. Hence, the characteristic curve for the operational relay R_i can be taken from a section of the selectable pronouncement of IEC rules and can be characterized as follows:

$$T_{op} = TMS_i \left(\frac{\alpha}{\left(I_{fi}/I_{pi}\right)^k - 1} \right), \tag{2}$$

where α and k are stable parameters that illustrate the relay features and are most likely equal to $\alpha = 0.14$ and $k = 0.02$ for a normal inverse-type relay. The terms I_{pi} and TMS_i are the pickup current and time multiplier setting of the i^{th} relay, respectively, while I_{fi} is the fault current moving through relay R_i.

$$PSM = \frac{I_{fi}}{I_{pi}}, \tag{3}$$

where I_{pi} is the primary or main pickup current and PSM stands for the plug setting multiplier and

$$T_{op} = TMS_i \left(\frac{\alpha}{(PSM)^k - 1} \right). \tag{4}$$

Condition 4 shows the nonlinear behaviour because of the variable factor of *PSM*. These problems can be converted into linear programming by assuming that the *PSM* is constant and taking the operational time of the relays, which is a linear function of the *TMS*. In the case of a linear problem, all the parameters are kept constant except for *TMS*, which is continual, so condition 4 becomes:

$$T_{op} = a_\rho (TMS_i), \tag{5}$$

where

$$a_\rho = \frac{\alpha}{(PSM)^k - 1}. \tag{6}$$

Therefore, the objective function can be expressed as follows:

$$\min f = \sum_{i=1}^{n} a_\rho (TMS_i). \tag{7}$$

2.1. Constraints. The aggregate operational time can be limited under two sorts of requirements, containing the limitations of the relay factor and the constraints coordination. The primary limitations comprise the cutoff points of the *TMS*, while the alternate requirements are pertinent to the coordination of the primary/backup relays. The bounds on the constrained problem can be seen as follows:

$$TMS_i^{\min} \le TMS_i \le TMS_i^{\max}, \tag{8}$$

$$T_j \ge T_i + CTI, \tag{9}$$

where the parameters T_i and T_j are the primary (or main) and backup (or secondary) relay operating times, respectively, and *CTI* is the coordination time interval.

3. JAYA Algorithm

The JAYA algorithm is a recently developed populace-built merger method for resolving different types of optimization problems, including the constrained and unconstrained problems developed by Rao in 2016 [35]. The key objective of the JAYA algorithm is that once the solution is achieved for a particular problem, the optimal result must be reached, thereby simultaneously avoiding the worst result. JAYA is a Sanskrit word meaning victory. The JAYA algorithm dependably endeavours victory by achieving accomplishments for discovering an optimal solution and attempts to overlook discontent by moving a long way from the worst solution. The JAYA algorithm attempts extraordinary endeavours to successfully discover the genuine result and solution, so it is named the JAYA algorithm. This optimization technique is very pretentious in an application perspective. Additionally, it contains noalgorithm-specific parameters and congregates to optimum elucidation in reasonably fewer number of function evaluations. The main advantage of the JAYA algorithm compared to further evolutionary algorithms is that it is unrestricted to algorithm-specific parameters and utilizes only two common parameters, that is, population size and the number of iterations. In cases of other optimization techniques, which require a scaling factor and crossover prospect, for example, when a particle swarm optimization needs an inertia weight, the learning factor and acceleration coefficient are used for the initial initialization. In this way, an imperative advantage of the JAYA calculation is its expert abilities, as far as ignoring the endeavour of changing constraints and reducing the time required for the optimization process. There are many applications of the JAYA algorithm in different research areas. In [36], JAYA was used for thermal devices. In [37], the JAYA algorithm was used in a linear power system to find an interconnection. In [38], JAYA was used in the area of modern machining processes. In [39], an optimal power flow solution was resolved by JAYA. In [40], elitist-JAYA was used for design optimization of heat exchanger. In [41], JAYA was used for maintenance consideration of heat exchanger. In [42, 43], JAYA was used to solve different engineering optimization problems. In [44], JAYA was used for the optimization of an integral controller. In [45, 46], an economic load dispatch optimization was validated using different version of JAYA.

Suppose $f(x)$ is an objective function with D dimensional factors $(j=1,2,\ldots,D)$, and $x_{i,j}$ is the estimation value of the j^{th} variable for the i^{th} competitor solution. Thus, $xi=(x_{i,1}, x_{i,2},\ldots, x_{i,D})$ is the position of the i^{th} candidate solution. The best competitor solution $x=(x_{best,1}, x_{best,2},\ldots, x_{best,D})$ has the best estimation of $f(x)$ in the present populace, while the worst candidate solution $x_{worst}=(x_{worst,1}, x_{worst,2},\ldots, x_{worst,D})$ is the estimation of $f(x)$ in the present populace. At that point, $x_{i,j}$, is simplified using Eq. (10).

$$x'_{i,j} = x_{i,j} + rand_1 \cdot \left(x_{best,j} - \left|x_{i,j}\right| - rand_2 \cdot \left(x_{worst,j} - \left|x_{i,j}\right|\right)\right). \tag{10}$$

Where $x_{best,j}$ and $x_{worst,j}$ are the values of the j^{th} variable for the best and worst solutions, respectively. $x'_{i,j}$ is the updated value of $x_{i,j}$ and $\left|x_{i,j}\right|$ is the absolute value of $x_{i,j}$. rand_1 and rand_2 are two equally disseminated arbitrary numbers within [0, 1]. In Eq. (10), the term $\mathrm{rand}_1.\left(x_{best,j} - \left|x_{i,j}\right|\right)$ illustrates the affection of the clarification that attracts the best solution and improves the worth of the superlative clarification in each iteration. Exploring the JAYA optimization technique, once the solution is achieved, it moves closer to the finest result and starts moving away from the worst solution. In this entire procedure, the JAYA algorithm seeks to achieve victory by forthcoming to the preeminent result; thus, it is entitled as JAYA.

1. Initialize population size (IPZ), number of design variables and meeting criteria, number of fitness function evaluations (FFE)
2. Analyse the fitness function value for each candidate;
3. FEE = NP;
4. While *FEE < Max_FEE* **do**
5. Select the finest candidate x_{best} and the worst candidate x_{worst} from the population;
6. **For** i = 1 to NP **do**
7. Select the fitness function value for the updated candidate;
8. FEE = FEE + 1;
9. Accept the new solution if it is better than the old one
10. **End for**
11. **End while**.

Algorithm 1: The pseudocode of JAYA algorithm.

3.1. Structure of JAYA. In view of the previously mentioned explanations, the pseudocode of the JAYA optimization technique can be condensed in Algorithm 1. In addition, the flowchart of JAYA is shown in Figure 1. It can be seen that the configuration of JAYA is straightforward and unique, and no extra parameters are required for the initialization in the JAYA; that is, JAYA is likewise unrestricted from algorithm-specific parameters.

4. Results and Discussion

A proper code has been generated in MATLAB software to find the optimal value of the OCR in a single- and multi-loop distribution network using JAYA. The efficiency and performance of JAYA were tested for the different single- and multi-loop systems, and it was found that JAYA gave the most satisfactory and even better results in all case studies. Three case studies were used, and the system details of all the case studies can be seen in references [23, 29, 47, 48]. In each case study, the following JAYA factors were used.

Populace size = 50.
A maximum number of iterations = 200.

The far-reaching clarification of the issue plan and the use of JAYA to locate the optimal resolution are demonstrated for all case studies.

4.1. Case 1. As shown in Figure 2, a multi-loop network with 6 OCRs is taken into account and with negligible line charging admittances. A different combination and configuration of primary/backup pairs are modelled depending on the location of fault currents in different feeders.

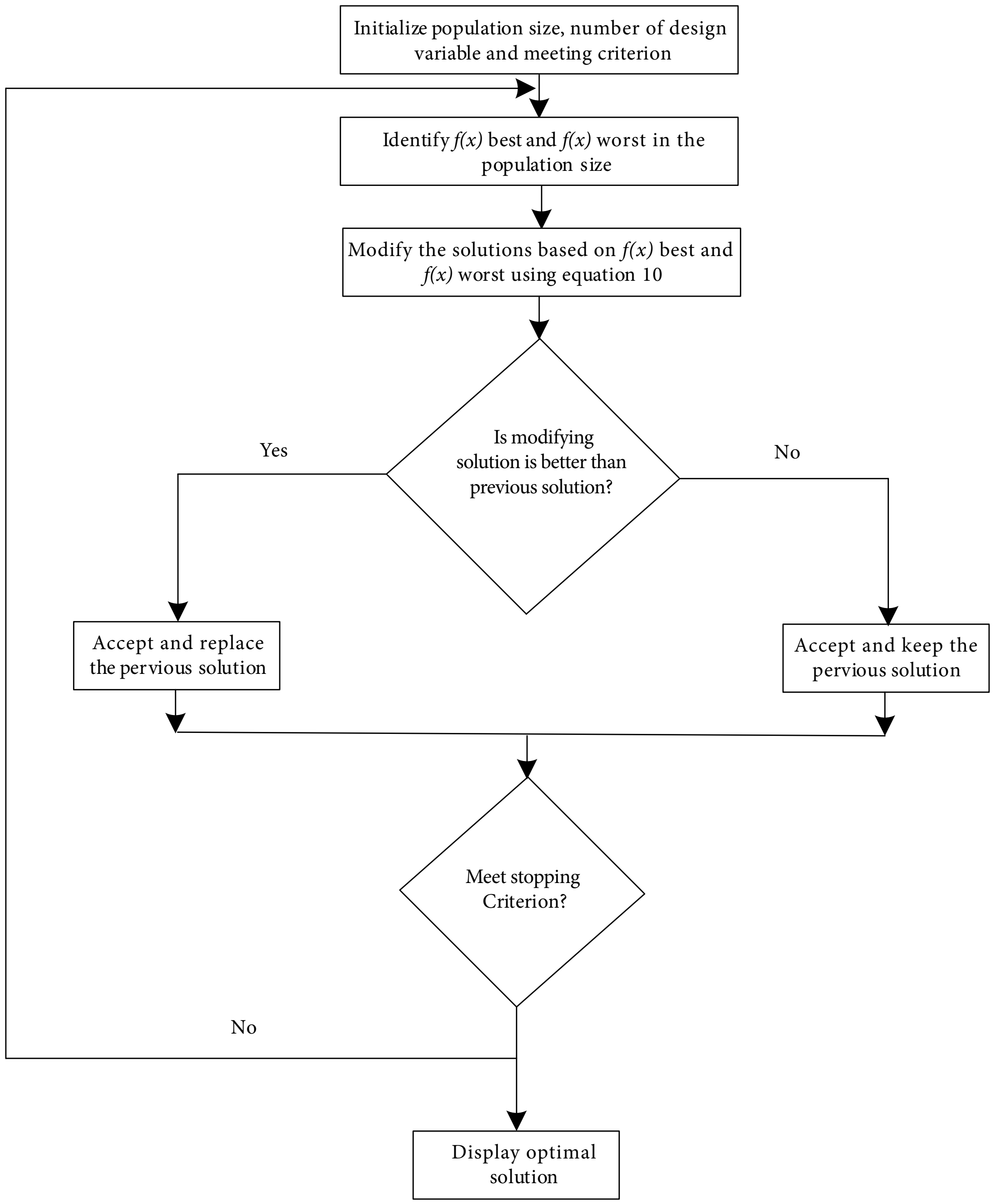

Figure 1: The flowchart of JAYA.

4.1.1. Mathematical Modelling of Problem Formulation. Table 1 shows the line data of the system. Table 2 shows the primary/backup pair of relays. For this illustration, 4 fault locations considered are depicted in Figure 2. Table 3 shows the CT ratios and plug settings. Table 4 shows a_ρ constant and the current seen by relays for different fault locations.

In this illustration, the entire number of constraints that arise is eleven; six constraints are due to bounds on the relay operating time, and four constraints are by reason of the coordination criteria. The minimum operating time (MOT) of each relay is 0.1 s. The *TMS*s of all six relays are x_1–x_6.

The optimization problem can be formulated as follows:

$$\min z = 102.404x_1 + 6.0651x_2 + 98.758x_3 + 24.403x_4 + 35.319x_5 + 11.539x_6. \tag{11}$$

The constraints arising as a result of the MOT of the relays are as follows:

$$3.646x_1 \geq 0.1, \tag{12}$$

$$6.055x_2 \geq 0.1, \tag{13}$$

$$8.844x_3 \geq 0.1, \tag{14}$$

$$8.844x_4 \geq 0.1, \tag{15}$$

$$4.044x_5 \geq 0.1, \tag{16}$$

$$11.539x_6 \geq 0.1. \tag{17}$$

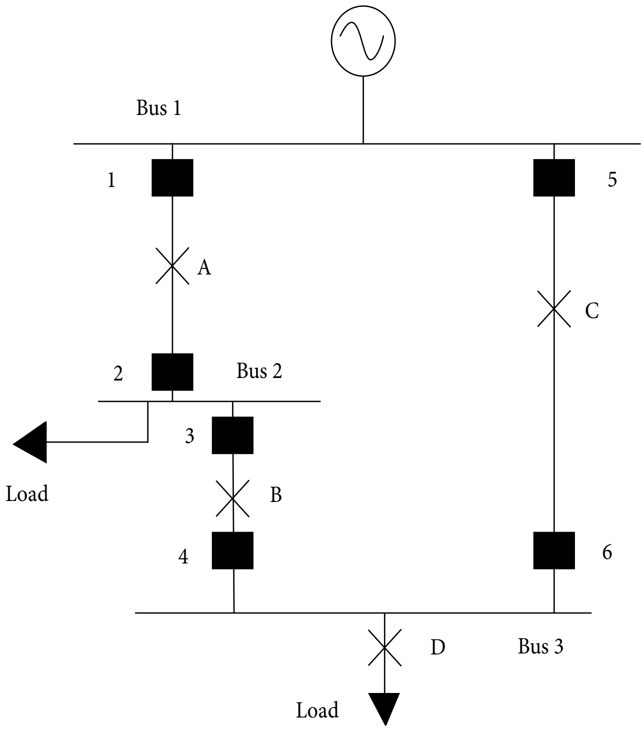

Figure 2: A single end-loop distribution system.

Hence, the constraints mentioned in equations (13) to (17) oppose the constraints of the minimum value of the *TMS*. However, these constraints are renovated as follows:

$$x_2 \geq 0.025, \tag{18}$$

$$x_3 \geq 0.025, \tag{19}$$

$$x_4 \geq 0.025, \tag{20}$$

$$x_5 \geq 0.025, \tag{21}$$

$$x_6 \geq 0.025. \tag{22}$$

The constraints arising as a result of the coordination of relays with CTI taken as 0.3 are as follows:

$$15.55x_4 - 6.065x_2 \geq 0.3, \tag{23}$$

$$8.844x_1 - 8.844x_3 \geq 0.3, \tag{24}$$

$$8.844x_5 - 8.844x_4 \geq 0.3, \tag{25}$$

$$75.91x_3 - 11.53x_6 \geq 0.3, \tag{26}$$

$$13.998x_1 - 13.998x_3 \geq 0.3. \tag{27}$$

4.1.2. Application of JAYA. To implement JAYA into the proposed idea, the objective function had been first changed to an unconstrained issue by incorporating the limitations of relay into the objective function, as discussed in Section 2. The lesser and higher limit of the entire *TMS* of the relay is deliberated as between 0.025 and 1.2, except for x_1, which is considered as 0.027. The limitations owing to the relay coordination defined by equalities (23) to (27) were merged in the optimization problem by means of a penalty technique, and accordingly, the problem was transformed into an unconstrained optimization problem. Now to validate JAYA, a populace capacity of 50 is used (i.e., candidate arrangements, six planned factors x_1 to x_6, and 200 generations as the meeting standard). The assessment of the factors in each populace was confined by lesser and higher bounds. The populace was carried to the fitness function, and the corresponding values of the objective function are recognized. By performing 200 iterations, the optimum values of the obtained *TMS* are given as in Table 5. Table 5 depicts the optimal *TMS* value acquired by the depicted technique for this illustration and assessment with the aforementioned techniques. The objective function

Table 1: Line data for Case 1.

Line	Impedance (Ω)
1–2	$0.08 + j1$
2–3	$0.08 + j1$
1–3	$0.16 + j2$

Table 2: Primary and backup relationships of the relays for Case 1.

Fault point	Primary relay	Backup relay
A	1, 2	–, 4
B	3, 4	1, 5
C	5, 6	-, 3
D	3, 5	1, -

Table 3: CT ratios and plug settings of the relays for Case 1.

Relay	CT ratio	Plug setting
1	1000/1	1
2	300/1	1
3	1000/1	1
4	600/1	1
5	600/1	1
6	600/1	1

Table 4: a_ρ Constants and relay currents for Case 1.

Fault point		Relay 1	2	3	4	5	6
A	I_{relay}	6.579	3.13	-	1.565	1.565	-
	a_ρ	3.646	6.065	-	15.55	15.55	-
B	I_{relay}	2.193	-	2.193	2.193	2.193	-
	a_ρ	8.844	-	8.844	8.844	8.844	-
C	I_{relay}	1.096	-	1.096	-	5.482	1.827
	a_ρ	75.91	-	75.91	-	4.044	11.539
D	I_{relay}	1.644	-	1.644	-	2.741	-
	a_ρ	13.99	-	13.99	-	6.872	-

- Indicates the fault is not seen by the relay.

Table 5: Optimal *TMS* values for Case 1.

TMS	CPSO [22] (CTI ≥ 0.3)	CGA [23] (CTI ≥ 0.3)	RTO [27] (CTI ≥ 0.3)	FA [29] (CTI ≥ 0.3)	CFA [29] (CTI ≥ 0.3)	JAYA (CTI ≥ 0.3)
TMS 1	0.0589	0.0765	0.0590	0.027	0.027	0.0589
TMS 2	0.0250	0.034	0.0250	0.130	0.221	0.0250
TMS 3	0.0250	0.0339	0.0250	0.025	0.025	0.0250
TMS 4	0.0290	0.036	0.0290	0.025	0.025	0.0290
TMS 5	0.0630	0.0711	0.0650	0.025	0.029	0.062946
TMS 6	0.0250	0.0294	0.0250	0.489	0.363	0.0250
$T_{op}(z)$	11.87	15.88	11.93	16.25	14.39	11.8728

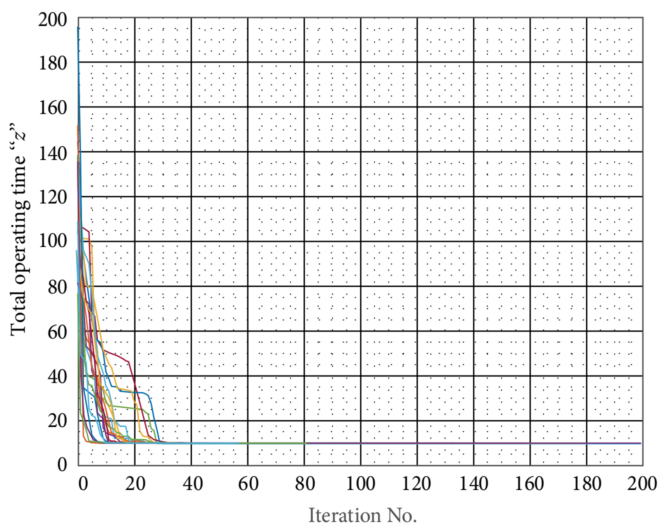

Figure 3: Convergence characteristics of JAYA for 20-time execution for Case 1.

value obtained over the span of recreation for the best applicant in each generation is depicted in Figure 3, which shows that the convergence is faster and a reasonable value is achieved in fewer iterations. The optimal value of the objective is found to be 11.8728 s by assuming CTI is 0.3 s, which is obtained in less than 25 iterations. The values appearing in Table 5 demonstrate that the JAYA algorithm gives a perfect course of action and a streamlined total working time up to the optimum values. The optimal values ensure that the relay will enact in the most reduced diminished conceivable time in the system for a fault at any portion. Figure 4 delineates a graphical portrayal of the time multiplier setting contrasted with the literature. The aggregate net pickup in time accomplished by the suggested JAYA is shown in Table 6, exhibiting the predominance and favourable circumstances of JAYA over the strategies said in the literature.

4.1.3. Comparison of JAYA with the CGA, FA, CFA, CPSO, and RTO Algorithms. To evaluate the performance of the suggested JAYA technique, the outcomes obtained by utilizing the JAYA technique are contrasted with the outcomes acquired by the other metaheuristic optimization methods, such as the continuous genetic algorithm (CGA), firefly (FA), chaotic firefly (CFA), continuous particle swarm (CPSO), and RTO optimization technique available in the literature as shown in Table 6. The JAYA outperforms the CGA, FA, CFA, and RTO in overall time gain and gives benefit of 4.0072 s, 4.3772 s, 2.8172 s, and 0.0572 s, respectively. However, in the case of CPSO, similar optimal result is obtained by using the JAYA algorithm with more execution time, where the computational and execution time taken by the CPSO to reach the optimum solution is approximately 8.007417 s. While in the case of JAYA, the computational and executive time is 0.041196 s when the CTI is 0.3 s. All in all, the algorithm that requires fewer capacity assessments to obtain a similar best arrangement (result) can be considered to be better when contrasted with an alternate algorithm [35]. Moreover, the JAYA algorithm is superior to the further optimization methods cited in the references in terms of using less computational exertion, which is a requisite to achieve the most superlative and finest solution. Be that as it may, the other algorithms specified in the literature require legitimate tuning of particular algorithm parameters, notwithstanding tuning of the regular controlling parameters. An adjustment in the tuning of the algorithm particular parameters impacts the viability of the algorithm, while in the case of JAYA, it is free from algorithm-specific parameters.

4.2. Case 2. A multi-loop system with 8 OCRs is depicted in Figure 5. A different combination and configuration of the

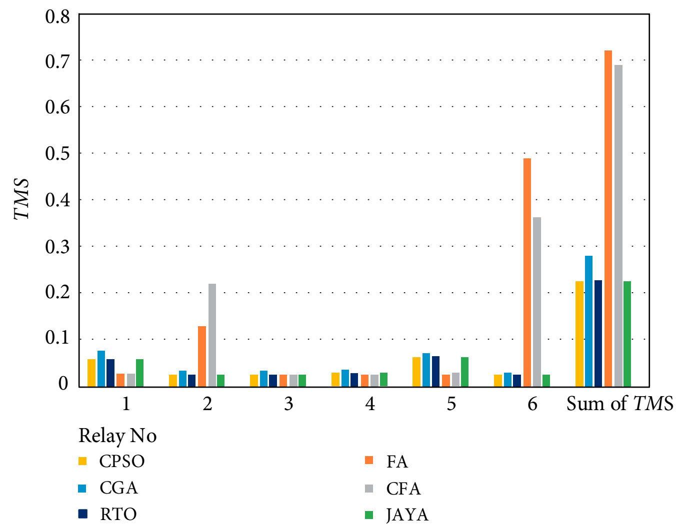

FIGURE 4: Comparison of the graphical representation of *TMS* with the CGA, FA, CFA, and CPSO and RTO algorithms for Case 1.

TABLE 6: Comparison of the total net gain time achieved by the proposed method for Case 1.

Method	Objective function	Net gain	$\Sigma\Delta(t)s$
CGA [23]	15.88	JAYA/CGA	4.0072
RTO [27]	11.93	JAYA/RTO	0.0572
FA [29]	16.25	JAYA/FA	4.3772
CFA [29]	14.39	JAYA/CFA	2.8172
JAYA	11.8728		

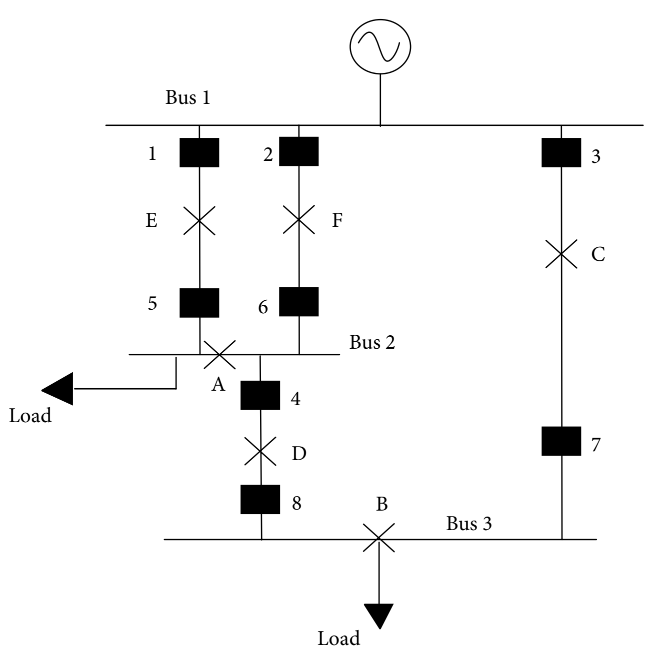

FIGURE 5: A multi-loop distribution system.

primary/backup pairs are modelled depending on the location of the fault currents in the different feeders. Six fault locations were deliberated. Table 7 shows the overall fault current and

TABLE 7: Primary/backup relationships and total fault current of the relays.

Fault point	T. fault current	Primary relay	Back relay
A	2330	1, 2, 8	-, -, 3
B	1200	3, 4	-, 1, 2
C	1400	3, 7	-, 4
D	1400	4, 8	1, 2, 3
E	2800	1, 5	-, 8
F	2800	2, 6	-, 8

- Indicates the fault is not seen by the relay.

the primary/backup association of the relay. Table 8 shows the relay current for various fault.

4.2.1. Mathematical Modelling of the Problem Formulation. In this case, study the total number of variables are 8, constraints bounded by the relay operational time are 8 and 9 constraints arise as a result of the coordination criteria. The dual of the problem will have 17 variables and 8 constraints. However, in this case, the value of CTI is taken as 0.6 s and the MOT of the relay is taken as 0.1 s. The *TMS*s of 8 OCRs are x_1–x_8.

The optimization problem can be formulated as follows:

$$\begin{aligned} \min z = {} & 28.975x_1 + 28.975x_2 + 37.736x_3 + 11.502x_4 \\ & + 3.297x_5 + 3.297x_6 + 4.9807x_7 + 30.7994x_8. \end{aligned} \tag{28}$$

The constraints arising as a result of the MOT of the relays are as follows:

$$2.971x_1 \geq 0.1, \tag{29}$$

$$2.971x_2 \geq 0.1, \tag{30}$$

$$5.584x_3 \geq 0.1, \tag{31}$$

$$4.980x_4 \geq 0.1, \tag{32}$$

$$3.297x_5 \geq 0.1, \tag{33}$$

Table 8: a_ρ Constants and relay currents for Case 2.

Fault point		Relay							
		1	2	3	4	5	6	7	8
A	I_{relay}	10	10	3.3	-	-	-	-	3.3
	a_ρ	2.971	2.971	5.749	-	-	-	-	5.749
B	I_{relay}	3.45	3.45	5.1	6.9	-	-	-	-
	a_ρ	5.584	5.584	4.227	3.551	-	-	-	-
C	I_{relay}	2	2	10	4	-	-	4	-
	a_ρ	10.035	10.035	2.971	4.9804	-	-	4.980	-
D	I_{relay}	5	5	4	10	-	-	4	-
	a_ρ	4.281	4.281	4.9804	2.971	-	-	-	4.9804
E	I_{relay}	20	6	2	-	8	-	-	4.9804
	a_ρ	2.267	3.837	10.035	-	3.297	-	-	10.035
F	I_{relay}	6	20	2	-	-	8	-	2
	a_ρ	3.837	2.267	10.035	-	-	3.297	-	10.035

- Indicates the fault is not seen by the relay.

Table 9: Optimal *TMS* values for Case 2.

TMS	RTO [27] (CTI ≥ 0.6)	GA [48] (CTI ≥ 0.6)	JAYA (CTI ≥ 0.6)
TMS 1	0.2521	0.2975	0.2412
TMS 2	0.2521	0.2975	0.2412
TMS 3	0.2000	0.2270	0.1903
TMS 4	0.1510	0.1730	0.1455
TMS 5	0.0303	0.0607	0.0303
TMS 6	0.0303	0.0607	0.0303
TMS 7	0.0250	0.0402	0.0250
TMS 8	0.0800	0.1129	0.0698
T_{op} (z)	26.681	31.883	24.953

$$3.297x_6 \geq 0.1, \tag{34}$$

$$4.980x_7 \geq 0.1, \tag{35}$$

$$10.035x_8 \geq 0.1, \tag{36}$$

Hence, the constraints stated in equations (31), (32), (35), and (36) oppose the constraints of the minimum *TMS* value. Hence, these constraints are renovated as follows:

$$x_3 \geq 0.025, \tag{37}$$

$$x_4 \geq 0.025, \tag{38}$$

$$x_7 \geq 0.025, \tag{39}$$

$$x_8 \geq 0.025. \tag{40}$$

The constraints arising as a result of the coordination of OCRs with the CTI taken as 0.6 s are as follows:

$$5.749x_3 - 5.749x_8 \geq 0.6, \tag{41}$$

$$5.584x_1 - 3.551x_4 \geq 0.6, \tag{42}$$

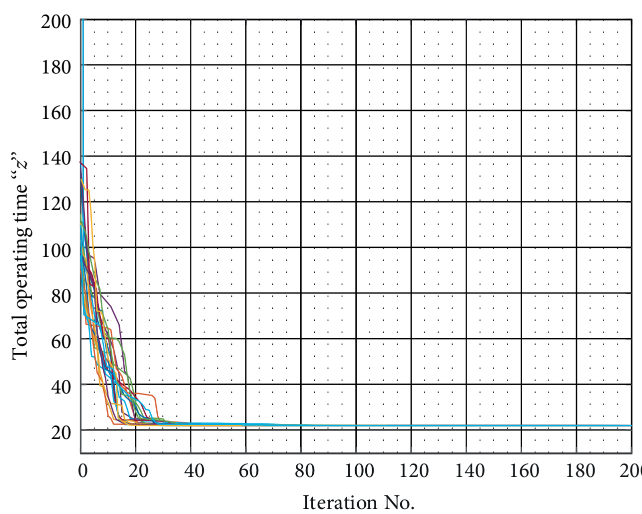

Figure 6: Convergence characteristics of JAYA for 20-time execution for Case 2.

$$5.584x_2 - 3.551x_4 \geq 0.6, \tag{43}$$

$$4.980x_4 - 4.980x_7 \geq 0.6, \tag{44}$$

$$4.281x_2 - 2.971x_4 \geq 0.6, \tag{45}$$

$$4.980x_3 - 4.980x_8 \geq 0.6, \tag{46}$$

$$10.035x_8 - 3.297x_5 \geq 0.6, \tag{47}$$

$$10.035x_8 - 3.297x_6 \geq 0.6. \tag{48}$$

4.2.2. Application of JAYA. The objective function was assessed utilizing the suggested JAYA algorithm with indistinguishable factors from that clarified in case study 1. The ideal estimations of the acquired *TMS* are given in Table 9, which demonstrates that the *TMS* and the overall operational time are optimized.

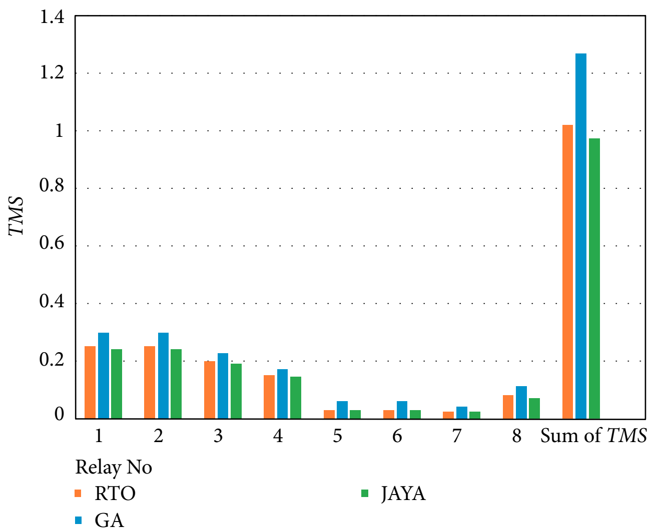

Figure 7: Comparison of the graphical representation of the optimal *TMS* with the RTO algorithm and GA for Case 2.

Table 10: Comparison of the total net gain time achieved by the proposed method for Case 2.

Method	Objective function	Net gain	$\Sigma\Delta(t)$s
RTO [27]	26.681	JAYA/RTO	1.728
GA [48]	31.883	JAYA/GA	6.93
JAYA	24.953		

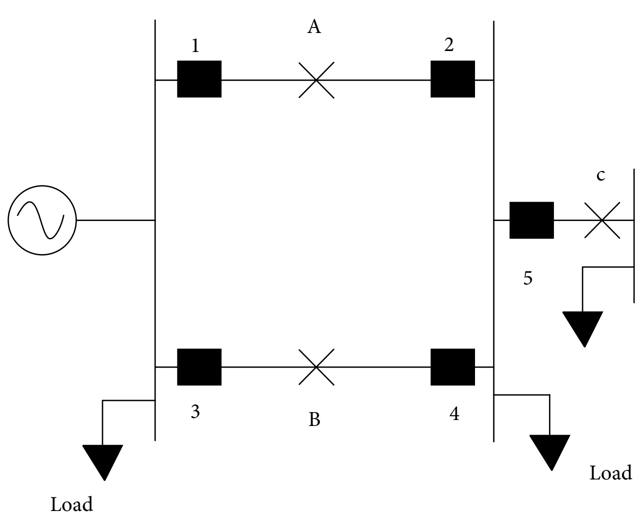

Figure 8: A parallel single end feeder distribution system.

The outcomes depicted in Table 9 guarantee that the OCRs operate at any proportional conceivable period for a fault at any time in the network and will also maintain coordination.

The objective function obtained over the span of the simulation for the preeminent candidate solution in every iteration is shown in Figure 6, which shows that the convergence is faster and obtains the optimum solution in fewer number of iterations. All the optimal values obtained by JAYA satisfy all the coordination constraints. Figure 7 depicts the optimized graphical representation of the *TMS* values of all eight relays with the other techniques mentioned in the literature. JAYA outperforms GA and RTO in this case study as well and obtaining the best result over RTO and GA.

The aggregate net time gain accomplished by the proposed JAYA is shown in Table 10, exhibiting the predominance and points of interest of JAYA over the genetic and RTO algorithms specified in the literature.

4.2.3. Comparison of JAYA with the Genetic Algorithm and RTO Algorithm. The outcomes obtained by utilizing the JAYA calculations are contrasted, and the outcomes acquired by the genetic and RTO algorithms are shown in Tables 9 and 10. JAYA outperforms the GA and RTO in attaining optimum values of

Table 11: Primary and backup relationships of the relay.

Fault point	Primary relay	Backup relay
A	1, 2	-, 3
B	3, 4	-, 1
C	5	1, 3

- Indicates no backup relay.

Table 12: CT ratios and plug setting of the relays.

Relay	CT ratio	Plug setting
1	300/1	1
2	300/1	1
3	300/1	1
4	300/1	1
5	100/1	1

Table 13: a_p Constants and relay currents for Case 3.

Fault point		Relay 1	2	3	4	5
A	I_{relay}	9.059	3.019	3.019	-	-
	a_p	3.106	6.265	6.265	-	-
B	I_{relay}	3.109	-	9.059	3.019	-
	a_p	6.265	-	3.106	6.265	-
C	I_{relay}	4.875	-	4.875	-	29.25
	a_p	4.348	-	4.348	-	2.004

Table 14: Optimal *TMS* values for Case 3.

TMS	FA[49] [29]	CFA[49] [29]	JAYA[49]	TPSM[50] [47]	JAYA[50]
TMS 1	0.032	0.032	0.069	0.069	0.069
TMS 2	0.016	0.047	0.01597	0.025	0.01597
TMS 3	0.121	0.091	0.069	0.069	0.069
TMS 4	0.016	0.016	0.01597	0.025	0.01597
TMS 5	0.104	0.094	0.0499	0.0499	0.0499
$T_{op}\ z(s)$	1.73	1.63	0.7286	2.27	2.1931

49, 50 represent the objective function mentioned in equations (49) and (50).

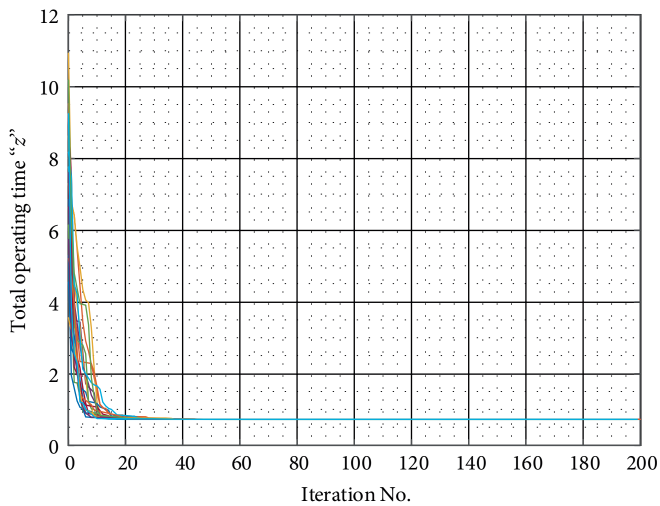

Figure 9: Convergence characteristics of JAYA for 20-time execution for Case 3 for the objective function mentioned in equation (49).

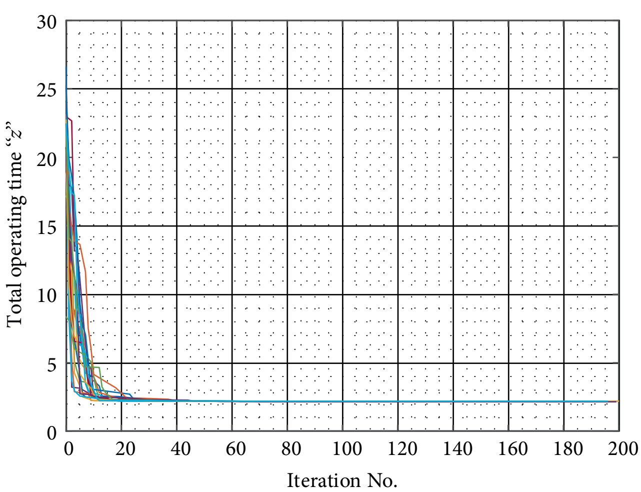

Figure 10: Convergence characteristics of JAYA for 20-time execution for case 3 for the objective function mentioned in equation (50).

the *TMS* and overall time gain, contributing an advantage of 6.93 s and 1.728 s over the GA and RTO algorithm, respectively. This overall time gain is sufficient given that it is a very small system. In all conditions, the JAYA performed outstandingly in minimizing the overall operational time up to an optimal value and will maintain proper coordination as well during a fault condition. Additionally, less computational and execution time is taken by JAYA to reach the optimum solution. In all the situations, the value obtained by JAYA for all the OCRs will fulfil the coordination constraints. Moreover, no desecration has been established regarding the coordination constraints.

4.3. Case 3. A parallel single end feeder distribution system that is nourished from a solitary end is shown in Figure 8 with five overcurrents. Three various fault locations were deliberated. The load current for the period of the fault was presumed to be negligible. Table 11 shows the primary and backup associations of the OCR CT. Table 12 shows CT ratios and plug settings of the OCRs.

4.3.1. Mathematical Modelling of the Problem Formulation. In this case study, the total number of constraints is nine; five constraints are bounded by relay operational time, and four constraints arise as a result of the coordination criteria. 0.1 s is the MOT of each OCR. The CTI is considered as 0.2 s. The *TMS*s of all the relays are $x_1 - x_5$. Table 13 shows a_p constant for various fault areas.

In this illustration, two problems are formulated from Table 13 to compare them properly with the literature.

The two-optimization problem can be formulated as follows:

$$z = 3.106x_1 + 6.265x_2 + 3.106x_3 + 6.265x_4 + 2.004x_5, \quad (49)$$

$$z = 13.719x_1 + 6.265x_2 + 13.719x_3 + 6.265x_4 + 2.004x_5. \quad (50)$$

The constraints arising as a result of the MOT of the relays are as follows:

$$3.106x_1 \geq 0.1, \quad (51)$$

$$6.265x_2 \geq 0.1, \quad (52)$$

$$3.106x_3 \geq 0.1, \quad (53)$$

$$6.265x_4 \geq 0.1, \quad (54)$$

$$2.004x_5 \geq 0.1, \quad (55)$$

The constraints arising as a result of the coordination of relays with the CTI taken as 0.2 s are as follows:

$$6.265x_3 - 6.265x_2 \geq 0.2, \quad (56)$$

$$6.265x_1 - 6.265x_4 \geq 0.2, \quad (57)$$

$$4.348x_1 - 2.004x_5 \geq 0.2, \quad (58)$$

$$4.348x_3 - 2.004x_5 \geq 0.2, \quad (59)$$

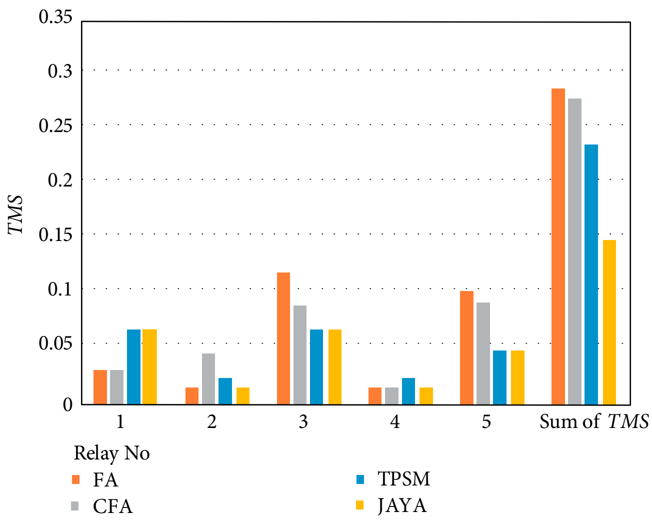

FIGURE 11: Comparison of the graphical representation of optimal *TMS* with FA, CFA, and TPSM algorithm for Case 3.

TABLE 15: Comparison of the total net time gain achieved by the proposed method for Case 3.

Method	Objective function	Net gain	$\Sigma\Delta(t)s$
FA[49] [29]	1.73	JAYA/FA[49]	1.01
CFA[49] [29]	1.63	JAYA/CFA[49]	0.91
TPSM[50] [47]	2.27	JAYA/TPSM[50]	0.0769
JAYA[49]	0.7286		
JAYA [50]	2.1931		

49, 50 represent the objective function mentioned in equations (49) and (50).

4.3.2. Application of JAYA. The objective function was utilized by the suggested JAYA algorithm with indistinguishable parameters. The optimal values of the *TMS* and the total operating time attained are given in Table 14, which likewise furnishes the similar aftereffect of JAYA with other numerical and developmental improvement strategies in the literature. In this delineation, no infringement or miscoordination of the relay has been discovered. It has been discovered that the time taken by relay R1 to start its activity is the slightest for a fault at point A and will need additional time for a fault at points B and C. Table 14 guarantees that the relay will effort at any proportion at any conceivable time for a fault at any time in the system. The objective function value obtained during the course of the simulation for the finest candidate arrangement in every iteration appears in Figures 9 and 10, which validates that the convergence is prompter and acquires the preeminent values in fewer iterations. All the *TMS* values obtained for OCR values fulfilled all the coordination limitations. Figure 11 portrays the streamlined graphical portrayal of the *TMS* values of all five relays with the other optimization methods stated in the references. Additionally, the JAYA outperformed the TPSM, FA, and CFA in this case study and obtained the satisfactory and best results, rather than another optimization algorithm. Table 15 shows the overall time gain accomplished by the suggested JAYA, exhibiting the predominance and favourable circumstances of JAYA over the TPSM algorithm, and FA and CFA specified in the references.

4.3.3. Comparison of JAYA with the FA, CFA, and TPSM Algorithm. To assess the execution of the suggested JAYA technique, the results obtained by utilizing the JAYA technique are differentiated with the results acquired by the other optimization methods, that is, the two-phase simplex method (TPSM), FA and CFA optimization techniques available in the references, as depicted in Table 15. The JAYA outperforms the FA and CFA in overall time gain, contributing an advantage of 1.01 s and 0.091 s for the optimization problem stated in equation (49). In the second optimization problem stated in equation (50) of Case 3, the JAYA is again contributing an improvement of 0.0769 s over the TPSM algorithm, respectively. The optimum value of the objective function is determined to be 0.7286 s for the objective function depicted in equation (49) and 2.1931s for the objective function depicted in equation (50), which is obtained in less than 25 iterations. Figure 11 portrays the streamlined graphical portrayal of the *TMS*, which demonstrates that the *TMS* is minimized up to ideal and optimal values.

5. Conclusion

In this paper, the JAYA algorithm is suggested to exactly and progressively evaluate the constraints of various OCR models. The aforementioned JAYA technique does not involve any parameters for tuning and hence is simple to implement. JAYA is analysed over parameter identification issues of OCR models. The simulation results demonstrate that JAYA has a better performance in terms of precision and consistency compared with other methods in the literature. The results obtained by JAYA technique effectively minimize all the three models of the issue. The performance of JAYA can be seen from the minimum function estimation acquired by the JAYA to reach the optimal value compared to other algorithms from the literature.

In Case 1, the objective function value is minimized up to optimum value by JAYA and gives an advantage in total net gain in time of 4.0072 s, 0.0572 s, 4.3772 s, and 2.8172 s over CGA, RTO, FA, and CFA. In case 2, the JAYA gives a total net gain in time of 1.728 s and 6.93 s, over RTO algorithm and GA, while in case 3, the JAYA gives a total net gain in time of 1.01 s, 0.91 s, and 0.0769 s over the FA, CFA, and TPSM algorithm. Thus, JAYA is a hopeful candidate solution for solving the constraint identification problem of OCR models.

In the future work, this technique will be used to solve issues of OCR and DOCR of higher and more complex case studies in power systems.

Nomenclature

CT: Current transformer
CTI: Coordination time interval
CFA: Chaotic firefly algorithm
CGA: Continuous genetic algorithm
CPSO: Continuous particle swarm
DOCR: Directional overcurrent relay
IPZ: Initialize population size
FFE: Fitness function evaluation

I_{fi}: Fault current
I_{pi}: Pickup current
FA: Firefly algorithm
RTO: Root tree optimization
GA: Genetic algorithm
MOT: Minimum operating time
PSM: Plug setting multiplier
OCR: Overcurrent relay
TMS: Time multiplier setting
TPSM: Two-phase simplex method
IEC: International electrotechnical commission.

Data Availability

The data used to support the finding of this study are included within the article.

Disclosure

Authors Abdul Wadood and Tahir Khurshaid are consider as co-first author.

Conflicts of Interest

The authors declare that they have no conflict of interest.

Authors' Contributions

Authors Abdul Wadood and Tahir Khurshaid are consider as co-first author.

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