Optimal Coordination of Over Current Relays Using Teaching Learning Based Optimization Algorithm

BHAGYARANI DUMALA
Electrical and Electronics engineering department
V.R.Siddhartha Engineering College
Vijayawada, Andhra Pradesh, India

K. SRIKANTH

ABSTRACT

Short circuit conditions can happen unexpectedly in any part of a power system at any time due to various physical problems. Such situations cause a large amount of fault current flow through some power system apparatus. The occurrence of the fault is harmful and must be isolated quickly by a set of protective devices. The duty of protective systems is the timely detection of fault and removing it from the power network. One of the most important protective elements that are used in power networks is over current relays. In this article, a new algorithm is presented to solve the optimization problem of coordination of over current relays by using Teaching Learning based Optimization Algorithm. Optimal relay coordination problem is to protect the distribution system within minimum possible time with high reliability. Relay coordination problem is a constrained optimization problem, which can be solved using conventional and heuristic optimization methods. The present work to solved optimal relay coordination problem for IEEE 3 bus and 8 bus test systems using Teaching learning Based optimization (TLBO) algorithm to get the minimum possible operating times while maintaining coordination among all relays in the distribution system.

Keywords:*Teaching Learning Based Optimization Algorithm, Distribution system, optimization, over current relay coordination.*

I INTRODUCTION

In a power system failure of components is inevitable as major components in the power system are subjected to ambient conditions. When a fault happens on any part of the power system, the relays detect the atypical conditions and operate. The relays send trip signal to the circuit breaker which performs the function of circuit interruption. The circuit breaker isolates the defective element from the rest of the system. The main function of protection system is to isolate the minimum possible part of power system at a fault or an atypical condition. When a fault happens in a power system, it should always be detected by two different protection relays. The protection relays are normally chosen Main and Backup protection. Over current relays are mainly used for transmission and sub transmission protection system. To consider comprehensive coordination, an over current relay with over current and finally a distance relay with an over current one when one of them is considered to be main relay and other as backup must be coordinated. In many transmission systems the main protection schemes use the directional over current relays are used as a secondary protection.

When the main protection fails to operate, the first stage backup protection should operate. The determination of time delay for the operation of all backup relays is known as coordination of protection system. Several optimization methods are proposed for coordination of over current relays. The optimal coordination of over current relays has been performed using linear programming techniques such as

- Simplex,
- Two phase simplex,
- Dual simplex methods.

The optimal solution is made by constraints only in. The disadvantage in the above method is that an optimal solution is not obtained if the constrains are not fulfilled. The optimal coordination by evolutionary algorithm may have two problems, miscoordination and lack of a solution. This is because optimization techniques as based on an initial guess and can be trapped in local maximum or minimum values. The intelligent optimization method using Genetic Algorithm does not have this problem. For optimal coordination of relays the critical fault locations have to be determined. The discrimination time between backup and main relays are minimum at critical fault points. The coordination of relays is done based on the constraints derived from values of Δt for critical fault locations. In all existing mathematical coordination methods, fixed characteristics are applied for all over current relays. To achieve optimal coordination the best characteristics for over current relay is required. In this paper the best characteristics of over current relay is selected by genetic algorithm for optimal coordination. In this method the constraints are included in the objective function.

A novel optimization method, 'Teaching–Learning-Based Optimization', is proposed. The method involves less computational effort for large scale problems. The method can be used for engineering design optimization applications.

II PROBLEM FORMULATION

In solution of relays coordination problem achieving minimum operation time and have no mis-coordination is very important.The aim of the coordination problem is to minimize the t operating times of primary and backup relays as follows[1]:

$$\sum_{i=1}^{m} t_i^2 + \alpha 2 \sum_{k=1}^{n} (\Delta_{tbk} - \beta_2 (\Delta_{tbk} - |\Delta_{tbk}|)^2 \quad (1)$$

Wheret_i represents operating time of relay R_i for fault in its primary protection zone, m is the number of primary relays. Moreover, the non-linear and well-known standard inverse definite minimum time characteristic curve based on IEC-60255-3 standard [2] has been considered in this paper. It is defined as

$$t_i = \frac{0.14 \times TMS_i}{\left(I_{c,i} / PS_i\right)^{0.02} - 1} \quad 2)$$

WhereTMS_i and PS_i are the TMS(Time multiplier setting) and PS(Plug setting) of relay R_i, respectively, and $I_{c,i}$ is the fault current passing through the operating coil of relay R_i.

$$\Delta t_{pbk} = t_{bk} - t_{pk} - CTI \quad (3)$$

WhereΔ_{tpbk} is the discrimination time between k_{th} P/B (Primary and backup) relay pairs, n is number of P/B relay pairs, and k indicates each P/B relay pairs which varies from 1 to n. t_{pk} and t_{bk} are the operating time of P/B relays, respectively.α1 and α2 are the positive weight factors to control the first and second terms of objective function.
The constraints subjected to the possible solution of relay coordination can be defined as follows.

A Boundary constraints on TMS

The boundary constraints on TMS can be stated as

$$TMS_{i,\min} \le TMS_i \le TMS_{i,\max} \quad (4)$$

Where$TMS_{i,min}$ and $TMS_{i,max}$ are the minimum and maximum value of TMS of relay R_i, which are provided by relay maker.

B Boundary constraints onPS

The boundary constraints on PS can be stated as

$$PS_{i,\min} \le PS_i \le PS_{i,\max} \tag{5}$$

Where$PS_{i,min}$ and $PS_{i,max}$ are the minimum and maximum values of PS of relay R_i. To make sure that the relay does not malfunction under normal load or small amount of overload condition, the minimum pickup current setting should be equal to or more than 1.25 times of the maximum load current. Similarly, maximum pickup setting should be less than or equal to 2/3 times of the minimum fault current, to make sure that the relay is sensitive to the smallest fault current [2– 4].

C Boundary constraints on operating time of relay

Any relay in the system needs certain minimum amount of operating time, also it cannot be allowed to take more time for the operation [2]. The constraints interconnected to the boundaries on operating time of relay can be stated as

$$t_{i,\min} \le t_i \le t_{i,\max} \tag{6}$$

Where$t_{i,min}$ and $ti_{,max}$ are the minimum and maximum operating time of Ri. In the coordination problem of Directional over Current relays, objective function (OF), coordination constraints and operating time constraints become non-linear due to the non-linear characteristic of relay. Therefore, the coordination problem is referred as complex and non-linear optimization problem and solved by considering large numbers of linear and non-linear constraints. To find the reasonable solution for satisfying these constraints, evolution for the objective function should be well designed.

III TEACHING LEARNING BASED OPTIMIZATION ALGORITHM

The TLBO algorithm is a teaching-learning process inspired algorithm based on the effect of influence of a teacher on the output of learners in a class. The algorithm describes two basic modes of the learning: (i) through teacher (known as teacher phase) and (ii) through interaction with the other learners (known as learner phase). In this optimization algorithm, a group of learners is considered as population and different subjects offered to the learners are considered as different design variables of the optimization problem and a learner's result is similar to the 'fitness' value of the optimization problem. The best solution in the total population is considered as the teacher. The design variables are actually the parameters involved in the objective function of the given optimization problem and the best solution is the best value of the objective function. The working of TLBO is divided into two parts, 'Teacher phase' and 'Learner phase'. Working of both the phases is explained below.

A Teacher Phase

It is the first part of the algorithm where learners learn through the teacher. For the period of this phase, a teacher tries to increase the mean result of the class in the subject taught by him or her depending on his or her capacity. At any iteration i, assume that there are 'm' number of subjects (i.e., design variables), 'n' number of learners (i.e., population size, k = 1, 2……… n) and Mj,i be the mean result of the learners in a particular subject 'j' (j = 1, 2,…, m) The best overall result $X_{total-kbest,I}$ considering all the subjects together obtained in the total population of learners can be considered as the result of best learner kbest. However, as the teacher is usually considered as a highly learned person who trains learners so that they can have better results, the best learner identified is considered by the algorithm as the teacher. The difference between the existing mean result of each subject and the corresponding result of the teacher for each subject is given by,

$$Difference\_Mean_{j,k,i} = r_i(X_{j,kbest,i} - T_F M_{j,i}) \tag{7}$$

Where, $X_{j,kbest,i}$is the result of the best learner in subject j. T_F is the teaching factor which decides the value of mean to be changed, and r_i is the random number in the range [0, 1]. Value of T_F can be either 1 or 2. The value of T_F is decided randomly with equal possibility as,

$$T_F = \text{round}[1+\text{rand}(0,1)\{2-1\}] \tag{8}$$

TF is not a parameter of the TLBO algorithm. The value of TF is not given as an input to the algorithm and its value is randomly decided by the algorithm using Eq. (8). After conducting a number of experiments on many benchmark functions it is concluded that the algorithm performs better if the value of TF is between 1 and 2. However, the algorithm is found to perform much better if the value of TF is either 1 or 2 and hence to simplify the algorithm, the teaching factor is suggested to take either 1 or 2 depending on the rounding up criteria given by Eq. (8). Based on the $\text{Difference\_Mean}_{j,k,i,}$ the existing solution is updated in the teacher phase according to the following expression.

$$X'_{j,k,i} = X_{j,k,i} + Difference\_Mean_{j,k,i} \tag{9}$$

Where, $X'_{j,\ k,\ i}$ is the updated value of $X_{j,\ k,\ i}$.$X'_{j,\ k,\ i}$ is accepted if it gives better function value. All the accepted function values at the end of the teacher phase are maintained and these values become the input to the learner phase. The learner phase depends upon the teacher phase.

B Learner Phase

It is the second part of the algorithm where learners increase their knowledge by interacting among themselves. A learner interacts randomly with other learners for increase his or her knowledge. A learner learns new things if the other learner has more knowledge than him or her. Considering a population size of 'n', the learning occurrence of this phase is explained below Randomly select two learners P and Q such that $X'_{total-P,i} \neq X'_{total-Q,i}$ (where, $X'_{total-P,i}$ and $X'_{total-Q,i}$ are the updated function values of $X_{total-P,i}$ and $X_{total-Q,i}$ of P and Q, respectively, at the end of teacher phase)

$$X''_{j,p,i} = X'_{j,P,i} + r_i(X'_{j,P,i} - X'_{j,Q,i}), If\ X'_{total-Q,j} < X'_{total-P,i} \tag{10}$$

$$X''_{j,p,i} = X'_{j,P,i} + r_i(X'_{j,Q,i} - X'_{j,P,i}), If\ X'_{total-Q,I} < X'_{total-P,i} \tag{11}$$

$X''_{j,P,I}$ is accepted if it gives a better function value. The Eqs. (11) and (12) are for minimization problems. In the case of maximization problems, the Eqs. (12) and (13) are used.

$$X''_{j,p,i} = X'_{j,P,i} + r_i(X'_{j,P,i} - X'_{j,Q,i}), If\ X'_{total-Q,j} < X'_{total-P,i} \tag{12}$$

$$X''_{j,p,i} = X'_{j,P,i} + r_i(X'_{j,Q,i} - X'_{j,P,i}), If\ X'_{total-P,I} < X'_{total-Q,i} \tag{13}$$

Teaching-learning-based optimization (TLBO) is a population-based algorithm which simulates the teaching-learning process of the class room. This algorithm requires only the common control parameters such as the population size and the number of generations and does not require any algorithm particular control parameters.

C Steps for the TLBO

The following steps give explanations to the TLBO algorithm.

Step 1: Initialize the population size or number of students in the class(N), number of generations (G), number of design variables or subjects (courses) offered which coincides with the number of units to place in the distribution system (D) and limits of design variables (upperU_L, and lower L_L, of each case).

Classify the optimization problem as: Minimize f(X), where f (X) is the objective function X is a vector for design variables such that $L_L \leq X \leq U_L$.

Step 2**:** Generate a random population according to the number of students in the class (N) and number of subjects offered (D).

Step 3:Calculate the average grade of each subject offered in the class.

Step 4:Based on the grade point (objective value) set the students (population) from best to worst.
Step 5:Change the grade point of each subject (control variables) of each of the individual student.
Step 6:Every learner improves grade point of each subject through the mutual interaction with the other learners. Each learner interacts randomly with other learners and hence facilitates knowledge sharing

D Flow chart for the TLBO

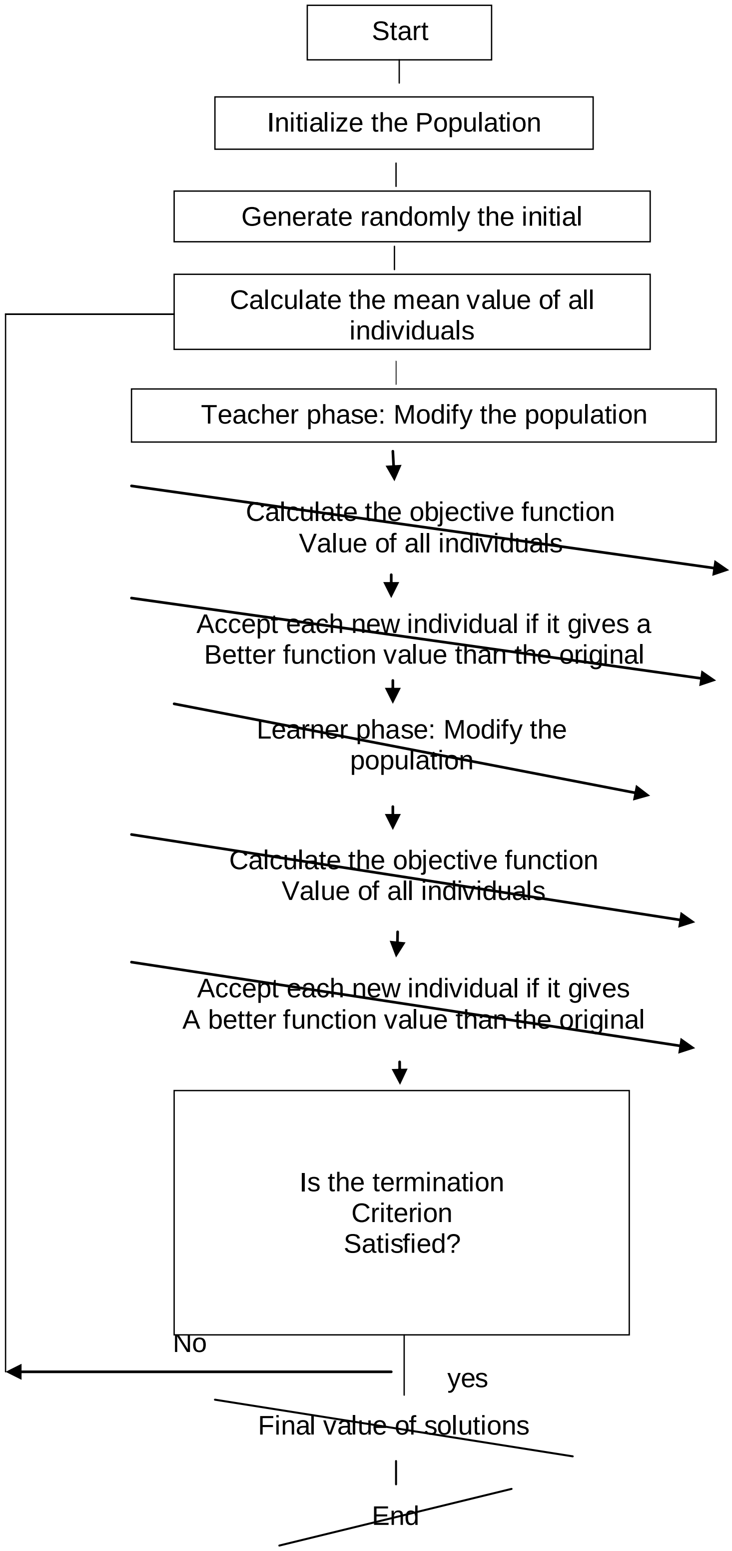

Fig 1 : Flow diagram of the TLBO algorithm

IV SYSTEM UNDER STUDY

System under study that is shown in Fig. 2 consists of 3 lines, 3 buses 2 Generators and 6 relays and fig 3 consists of 7 lines, 8 buses, 2 generators, 2 transformers and 14 relays [5-8].The information data of the network is given in Tables 1–3.

TABLE 1 :3Φ faults of the 3 – bus system

Primary (R_i)	***Fault current***	***Backup (R_j)***	***Fault current***	***CTR***
R_1	1978.90	R_5	175	300/5
R_2	1525.70	R_4	545	200/5
R_3	1683.90	R_1	617.22	200/5
R_4	1815.40	R_6	466.17	300/5
R_5	1499.66	R_3	384	200/5
R_6	1766.30	R_2	154.34	400/5

TABLE 2 :3Φ faults of the 8 – bus system

Primary (R_i)	***Fault current***	***Backup (R_j)***	***Fault current***	***CTR***
R_1	3232	R_6	3232	1200/5
R_2	5924	R_1	996	1200/5
R_2	5924	R_7	1890	1200/5
R_3	3556	R_2	3556	800/5
R_4	3783	R_3	2244	1200/5
R_5	2401	R_4	2401	1200/5
R_6	6109	R_5	1197	1200/5
R_6	6109	R_{14}	1874	1200/5
R_7	5223	R_5	1197	800/5
R_7	5223	R_{13}	987	800/5
R_8	6093	R_7	1890	1200/5
R_8	6093	R_9	1165	1200/5
R_9	2484	R_{10}	2484	800/5
R_{10}	3883	R_{11}	2344	1200/5
R_{11}	3707	R_{12}	3707	1200/5
R_{12}	5899	R_{13}	987	1200/5
R_{12}	5899	R_{14}	1874	1200/5
R_{13}	2991	R_8	2991	1200/5
R_{14}	5199	R_1	996	800/5
R_{14}	5199	R_9	1165	800/5

TABLE 3 : Optimization data for the 3 bus and8 bus systems

Type of bus	*TMS Min*	*TMS max*	*PS Min*	*PS Max*	*PS Mode*	*CTI (sec)*
3 - bus	0.1	1.1	1.5	5.0	Discrete	0.2
8 - bus	0.1	1.1	0.5	2.5	Discrete	0.3

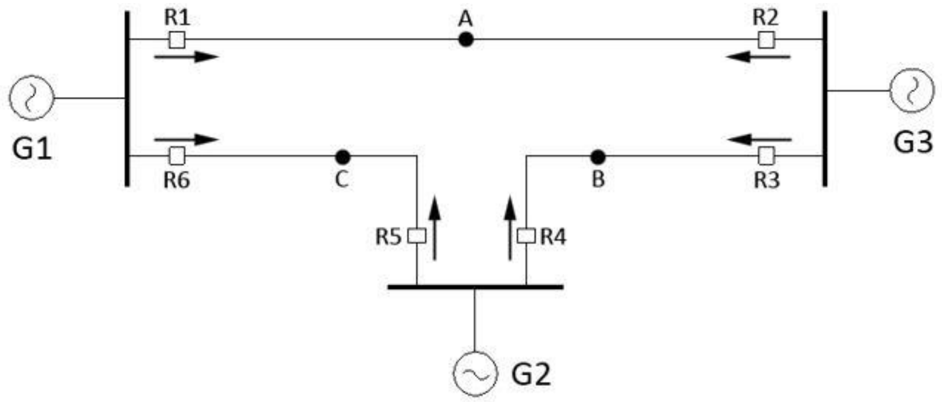

Figure 2 : 3 Bus Test System

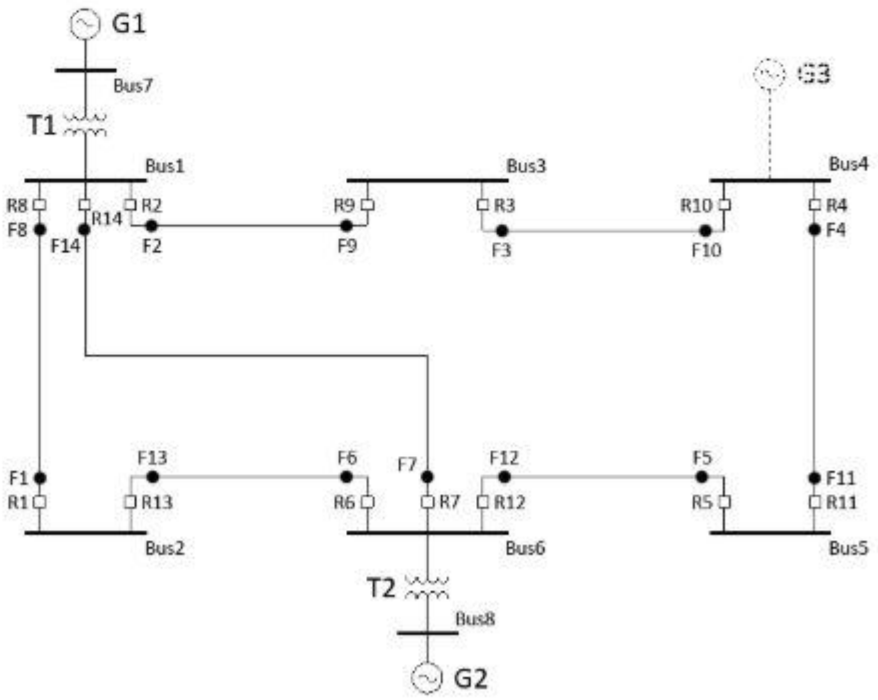

Figure 3 : 8 - Bus Test System

V RESULTS AND DISCUSSIONS

TABLE 4: TLBO parameters

TLBO parameters	Value
α_1	1
α_2	1
β_2	100
Iterations	100
N	10
D	2
CTI	0.2

As seen in table 4, the CTI depends upon the types of relays, operating time of circuit breaker, relay error and safety margin. Typically, the CTI is selected between 0.3 and 0.5s for electromechanical relays, whereas it is considered between 0.1 and 0.2s in microprocessor-based relays. α1, α2are the positive weight factors to control the first and second terms of objective function. Where β2 used to consider mis coordination, N, D are population size and number of design variables.

TABLE 5: Total operating time of P/B relays

3 bus - system	6.0925
8-bus system	14.1193

From table 5, it shows the total operating time of primary and backup relays. It gives the minimum total operating time of primary and backup relays. By reducing the discrimination time of P/B relay, the operating time of backup relays is also minimized.

TABLE 6: Relay settings obtained by objective function for IEEE 3 – bus system

Relay	TMS	PS
R_1	1.0760	1.5245
R_2	1.0927	1.8962
R_3	1.0812	4.1332
R_4	1.0932	1.6205
R_5	0.9397	1.5000
R_6	0.9953	1.5024

TABLE 7: Relay settings obtained by objective function for IEEE 8 bus - system

Relay	***TMS***	***PS***
R_1	1.1000	2.5000
R_2	1.0240	2.5000
R_3	1.1000	0.5000
R_4	1.1000	2.5000
R_5	1.1000	2.3772
R_6	0.1000	2.4322
R_7	1.1000	2.5000
R_8	1.1000	0.5000
R_9	1.1000	2.5000
R_{10}	1.1000	2.5000
R_{11}	0.9856	0.5000
R_{12}	1.0193	2.5000
R_{13}	1.0904	2.4049
R_{14}	1.1000	0.7798

From table 6 and 7, it shows the TMS and PS values of the relays. Table 5, gives the minimum operating time of the P/B relays, that corresponding values of TMS and PS are taken from table 8.

TABLE 8: Discrimination time of the P/B relays for 3 bus - system

Relay	**Discrimination time (Δ_{tb})**
R_1	0.3367
R_2	0.0076
R_3	0.0522
R_4	0.0613
R_5	0.0337
R_6	0.3378

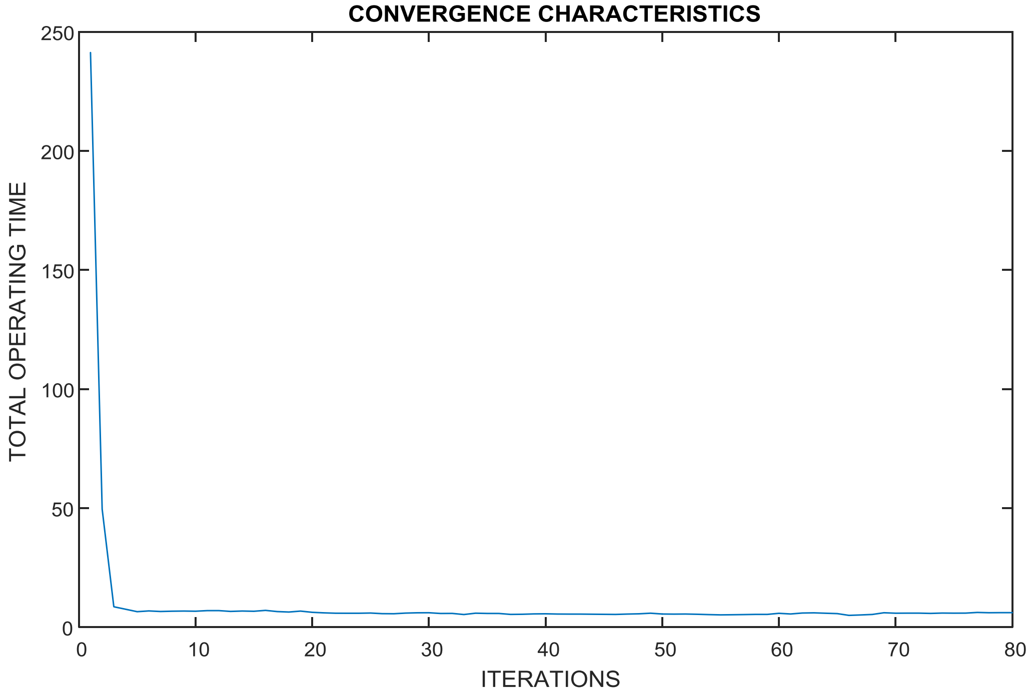

Fig 4: Convergence of TLBO for IEEE 3-bus network

Fig 4 shows the convergence of TLBO for IEEE 3-bus network. The convergence of the TLBO was plotted between objective function vs .number of iterations. In fig 4 we were observed gradually decrease of the objective function and it gives the better operating time of the relays.

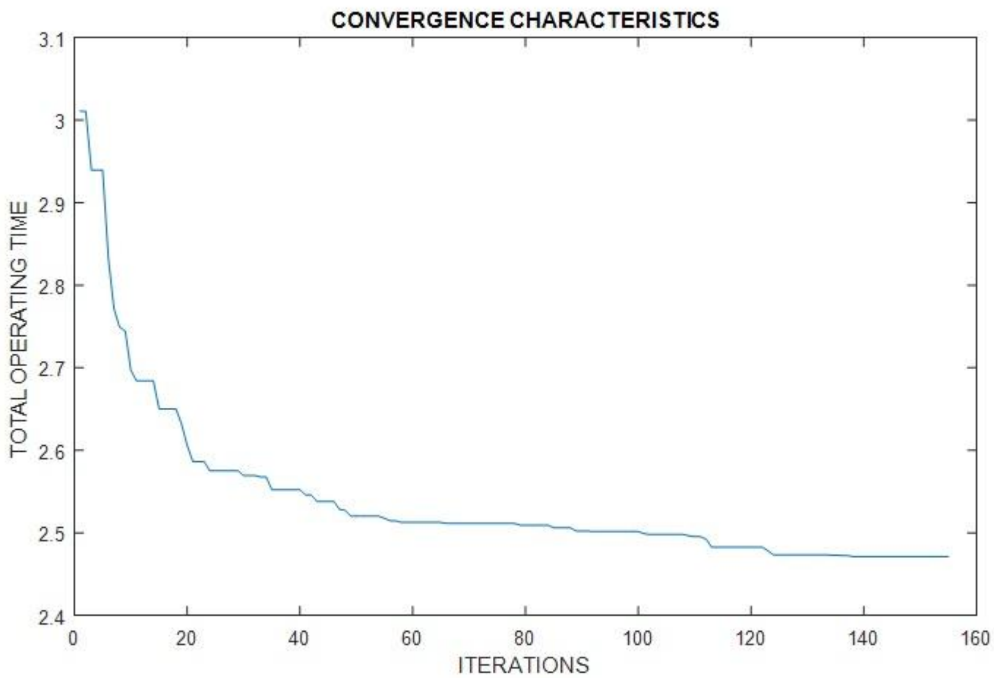

Fig 5: Convergence of TLBO for IEEE 8-bus network

Fig 5 shows the convergence of TLBO for IEEE 8-bus network. The TLBO method improves the performance of convergence characteristics, results in a less operating time compared to other works.

VI CONCLUSION

The Teaching Learning Based Optimization process can be used to solve the optimal placement and sizing problems of Distributed Generation units in various systems, in particular it can be implemented for radial distribution systems. In relay coordination optimization process, minimizing relays operating time is very important. In this paper Teaching Learning Based Optimization Algorithm is applied for relays coordination using IEEE 3 bus and 8 bus test systems. The results showed that the proposed TLBO technique is capable of finding superior TDS, PMS settings and minimum operating time of the P/B relays. This method works on the effect of influence of a teacher on learners.

REFERENCES

[1] Vipul N. Rajput, FarhadAdelnia, Kartik S. Pandya, "Optimal coordination of directional over current relays using improved mathematical formulation." IET Generation, Transmission &Distribution, Volume 12, Issue 9,15 May 2018, p. 2086 – 2094

[2] Bedekar, P.P., Bhide, S.R.: 'Optimum coordination of directional overcurrent relays using the hybrid GA-NLP approach', IEEE Trans. Power Deliv., 2011, 26, (1), pp. 109–119

[3] Noghabi, A.S., Sadeh, J., Mashhadi, H.R.: 'Considering different network topologies in optimal overcurrent relay coordination using a hybrid GA', IEEE Trans. Power Deliv., 2009, 24, (4), pp. 1857–1863

[4] Rajput, V.N., Pandya, K.S.: 'Coordination of directional overcurrent relays in the interconnected power systems using effective tuning of harmony search algorithm', Sust. Comput., Inform. Syst., 2017, 15, pp. 1–15

[5] Amraee, Turaj. "Coordination of directional overcurrent relays using seeker algorithm." IEEE Transactions on Power Delivery 27.3 (2012): 1415-1422.

[6] A. Urdaneta, R. Nadira, and L. Perez Jimenez, "Optimal Coordination of Directional Overcurrent Relays in Interconnected Power Systems," IEEE Transactions on Power Delivery, vol. 3, no. 3, pp. 903–911, Jul. 1988.

[7] H.H. Zeineldin, E.F. El-Saadany, and M.A. Salama, "Optimal Coordination of Directional Overcurrent Relay Coordination," *in* 2005 IEEE Power Engineering Society General Meeting, vol. 2, pp. 1101-1106, Jun. 2005.

[8] A.S. Braga, and J.T. Saraiva, "Coordination of Overcurrent Directional Relays in Meshed Networks Using the Simplex Method," in *Electrotechnical Conference, 1996. MELECON '96., 8th Mediterranean*, vol. 3, pp. 1535-1538, May 1996.