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CUSTOMER AND ENERGY BASED INDICES CONSIDERATION FOR RELIABILITY ENHANCEMENT OF DISTRIBUTION SYSTEM USING IMPROVED TEACHING LEARNING BASED OPTIMIZATION

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Abstract-This paper describes an algorithm for optimum modifications for failure rate and repair time for a radial distribution system. The modifications are with respect to a penalty cost function minimization. The cost function has been minimized subject to the energy based and customer oriented indices. Improved Teaching Learning based optimization (I-TLBO) has been used for optimization. The algorithm has been implemented on a sample radial distribution system.
Keywords- Failure rate, repair time, radial distribution systems, penalty cost function, Improved Teaching Learning based optimization (I-TLBO).

1. INTRODUCTION

Reliability evaluation of distribution systems is important from consumer's view-point. Outage customer oriented and energy based indices are important for analysis of distribution system. Considerable research efforts have been devoted to improve availability of supply due to distribution systems [1]. Preventive maintenance reduces failure rate whereas along with corrective repair availability of supply increases [2]. Gangel and Ringlee [3] initially presented modelling concepts for the individual components of distribution systems for reliability evaluation. Different techniques for evaluating reliability indices have been discussed in literature [4-10]. Pereira and Pinto [11] discussed modelling assumptions and computational aspects of a computational tool for composite system reliability evaluation. Su and Lii [12] used genetic algorithm for distribution system and obtained optimum failure and repair rates. The optimal design of reliability indices in an electrical distribution system and their impact to planning was discussed by Chang et al. [13]. Popov et al. [14] described an algorithm of reliability optimization for operational planning of distribution system. Meziane et al. [15] discussed reliability optimization using ant colony algorithm under performance and cost constraints. Sohn et al. [16] discussed a method for identifying the type and location for protection devices and switches on the pre routed distribution system using value based optimization. Bakkiyaraj and Kumarappan [17] presented a methodology for evaluating optimal reliability indices of system components for a composite electric power system based on state sampling non-sequential Monte Carlo simulation and using particle swarm optimization (PSO) algorithm. Louit et al. [18] presented a methodology for obtaining optimum interval for major maintenance action for a power network. An algorithm for evaluating optimum value of reliability indices for distribution system using gradient projection method was proposed by Sallam et al. [19].

This paper describes an algorithm for reliability improvement of a radial distribution system accounting constraints on energy based and customer oriented indices using Improved Teaching Learning based optimization algorithm. The algorithm propose based on teaching learning based algorithm is implemented on radial distribution system. Statistical analysis is also provided.

2. CUSTOMER ORIENTED AND ENERGY BASED RELIABILITY INDICES

EPRI (Electric Power Research Institute) has identified that most frequently used customer oriented indices are SAIFI, SAIDI, CAIDI and AENS. These indices are defined as follows [20]

System average interruption frequency index (SAIFI)

$$\text{SAIFI} = \frac{\sum \lambda_{sys,i} N_i}{\sum N_i}$$

System average interruption duration index (SAIDI)

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$$\mathrm{SAIDI} = \frac{\sum U_{sys,i} N_i}{\sum N_i}$$

Customer average interruption duration index (CAIDI)

$$\mathrm{CAIDI} = \frac{\sum U_{sys,i} N_i}{\sum \lambda_{sys,i} N_i}$$

Expressions for the evaluation of system failure rate and system unavailability for each load point are given as follows

$$\lambda_{sys,i} = \sum_{k \in S} \lambda_k$$

$$U_{sys,i} = \sum_{k \in S} \lambda_k r_k$$

S denotes the set of distributor segments connected in series up to i^{th} load point.

One of the most important energy based indices is average energy not supplied (AENS) which is given as follows.

$$\mathrm{AENS} = \frac{\sum L_i U_{sys,i}}{\sum N_i}$$

where Li is average load connected at i^{th} load point. Constraint is imposed on AENS by selecting a threshold value of this index.

3. PROBLEM FORMULATION

The cost function in penalty form has been assumed and is given as follows [21]

$$J = J_1 + J_2 \tag{1}$$

where J_1 represents total penalty on modifications in failure rates at each distributor segment and is expressed as

$$J_1 = \sum_{i=1}^{NC} \left[\frac{\lambda_i^0 - \lambda_i}{\lambda_i - \lambda_{i,min}} \right] \tag{2}$$

Where λ_i^0, $\lambda_{i,min}$ and λ_i are current, minimum achievable and modified failure rate of i^{th} segment respectively. NC denotes total number of distributor segments.

J_2 represents cost of modification in repair time for all the distributor segments and is given as follows

$$J_2 = \sum_{i=1}^{NC} \left[\frac{r_i^0 - r_i}{r_i - r_{i,min}} \right] \tag{3}$$

where r_i^0, r_i and $r_{i,min}$ represent current, modified and minimum achievable repair time for i^{th} segment. It is obvious that the lesser is the value of repair time the more is the penalty. It is assumed that modified repair time of a component is less than the current value.

Finally the objective function (1) is written as follows

$$J = \sum_i \frac{\lambda_i^0 - \lambda_i}{\lambda_i - \lambda_{i,min}} + \sum_i \frac{r_i^0 - r_i}{r_i - r_{i,min}} \tag{4}$$

The objective function as given by (4) is minimized subject to following constraints

$$\mathrm{SAIFI} \le \mathrm{SAIFI}_d$$

$$\mathrm{SAIDI} \le \mathrm{SAIDI}_d$$

$$\mathrm{CAIDI} \le \mathrm{CAIDI}_d$$

$$\mathrm{AENS} \le \mathrm{AENS}_d$$

$$\lambda_{i,min} \le \lambda_i \le \lambda_i^0, \qquad r_{i,min} \le r_i \le r_i^0$$

4. OVERVIEW OF IMPROVED TEACHING LEARNING BASED OPTIMIZATION (I-TLBO)

The teaching learning based optimization method is proposed by Rao et al. [22]. The method helps in obtaining global solution for continuous non-linear functions with less computational effort and high consistency. The TLBO method is based in the effect of the influence of a teacher on the output of learners in a class. First the initial population is generated having population size (NP) and the number of design variables (D), from uniform distribution between lower and upper limits of decision variables.

The mean of the population is obtained as follows

$$M_D = [m_1, m_2, \ldots. m_D] \quad (5)$$

Now the mean will be the new teacher, therefore

$$M_{new,D} = X_{teacher,D} \quad (6)$$

The difference between the mean is given by

$$Difference_D = r(M_{new,D} - T_F M_D) \quad (7)$$

TF is teaching factor and randomly selected as 1 or 2.

The modified population is updated as follows:

$$X_{new,D} = X_{old,D} + Difference_D \quad (8)$$

Accept $X_{new,D}$ if it gives better objective function value. Obtain X_{modified} from learners phase as follows:

if $f(X_i) < f(X_j)$, then $X_{\text{modified}} = X_{old} + r(X_i - X_j)$

Otherwise, $X_{\text{modified}} = X_{old} + r(X_j - X_i)$ (9)

X_i is the ith vector and X_j are randomly selected vector. Compare the objective function value of $X_{new,D}$ and X_{modified}. The objective function which provides least value will be the new population. The procedure is terminated if a maximum number of Teaching-Learning generations (k_{max}) have been executed.

The Improved teaching learning based optimization method is proposed by Rao et al. [23]. In the basic TLBO algorithm [22], the result of the learners is improved either by a single teacher (through classroom teaching) or by interacting with other learners. However, in the traditional teaching-learning environment, the students also learn during tutorial hours by discussing with their fellow classmates or even by discussion with the teacher himself/herself. Moreover, sometime students are self-motivated and try to learn by themselves. Furthermore, the teaching factor in the basic TLBO algorithm is either 2 or 1, which reflects two extreme circumstances where a learner learns either everything or nothing from the teacher. In this system, a teacher has to expend more effort to improve the results of learners. During the course of optimization, this situation results in a slower convergence rate of the optimization problem. Considering this fact, to enhance the exploration and exploitation capacities, some improvements have been introduced to the basic TLBO algorithm. Rao et al. [24, 25] made some modifications to the basic TLBO algorithm and applied the same to the optimization of a two stage thermoelectric cooler and heat exchangers. The previous modifications are further enhanced and a new modification is introduced to improve the performance of the algorithm, which consists of number of teachers, adaptive teaching factor, learning through tutorials, self-motivated learning.

5. RESULTS AND DISCUSSIONS

The I-TLBO algorithm developed in this paper for reliability enhancement has been implemented on a radial distribution system [21]. The system has in all seven load points (LP). The system contains seven feeder segments. Initial failure rate and average repair time for each distributor segment is provided in [21]. The same table also gives minimum reachable values of these variables. Average loads and number of customers (N_i) at each load point is provided in [21]. Table 1 presents the statistics of best fitness function values as obtained using I-TLBO, PSO and CAPSO based on 30 numbers of runs.

Fig.-1 shows the evolution of best fitness value (objective function) as obtained by I-TLBO algorithm. Table 2 shows the optimized set of decision variables along with least values of objective function as obtained by I-TLBO. These values are with respect to the best run in each case. Table 3 shows un-optimized and optimized values of the customer and energy based indices.

6. CONCLUSIONS

Customer and energy based reliability indices are of great significance in predictive reliability performance assessment of a distribution system. These indices are extensively used in power industry. All such indices depend on failure rate and repair time of each segment of distribution systems. An optimization method has been presented using I-TLBO to obtain optimum failure rate and repair times so as to achieve desired levels of the indices. A penalty cost function has been used for this purpose.

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Table 1- Statistics of best fitness function values as obtained using I-TLBO, PSO and CAPSO based on 30 numbers of runs.

Statistics	Technique		
	I-TLBO	CAPSO [21]	PSO [21]
Average value of best fitness function values	18.6589	19.0522	19.2545
Standard deviation	0.0147	0.0252	0.1445
Minimum value of best fitness function	18.7845	19.0214	19.0738
Maximum value of best fitness function	18.1899	19.1230	19.5737

Table 2- Optimized values of failure rates and repair times as obtained by I-TLBO, PSO, CAPSO, and DFP techniques.

Variables	Magnitudes as obtained by			
	TLBO	PSO [21]	CAPSO [21]	DFP [21]
1	0.2312	0.2395	0.2387	0.2401
2	0.0915	0.0991	0.0973	0.0948
3	0.1935	0.2065	0.2005	0.2001
4	0.1768	0.1831	0.1839	0.1830
5	0.1916	0.1956	0.1977	0.1982
6	0.0982	0.1000	0.1000	0.0999

7	0.0974	0.0999	0.1000	0.0989
r1	6.9034	6.9454	6.9291	6.8941
r2	7.7237	7.9565	7.7865	7.9261
r3	8.1345	7.7388	8.1588	8.2660
r4	11.4038	11.5192	11.7020	11.8820
r5	11.1467	11.3236	11.6383	11.2861
r6	7.9835	8.0000	7.9996	7.9757
r7	11.9832	12.0000	11.9931	11.9024
Objective function, J	18.3634	19.0738	19.0214	19.1054

Table 3- Current and optimized reliability indices.

S. No.	Index	Current values	Optimized values				Threshold values
			I-TLBO	PSO [21]	CAPSO [21]	DFP [21]	
1	SAIFI interruptions/customer	0.7200	0.4078	0.4150	0.4130	0.4127	0.5000
2	SAIDI hrs/customer	8.4500	3.3001	3.3056	3.3022	3.2991	4.0000
3	CAIDI hrs/customer interruption	11.7361	7.9267	7.9657	7.9955	7.9933	8.0000
4	AENS kWh/customer	26.4100	10.000	10.000	10.000	9.9968	10.000

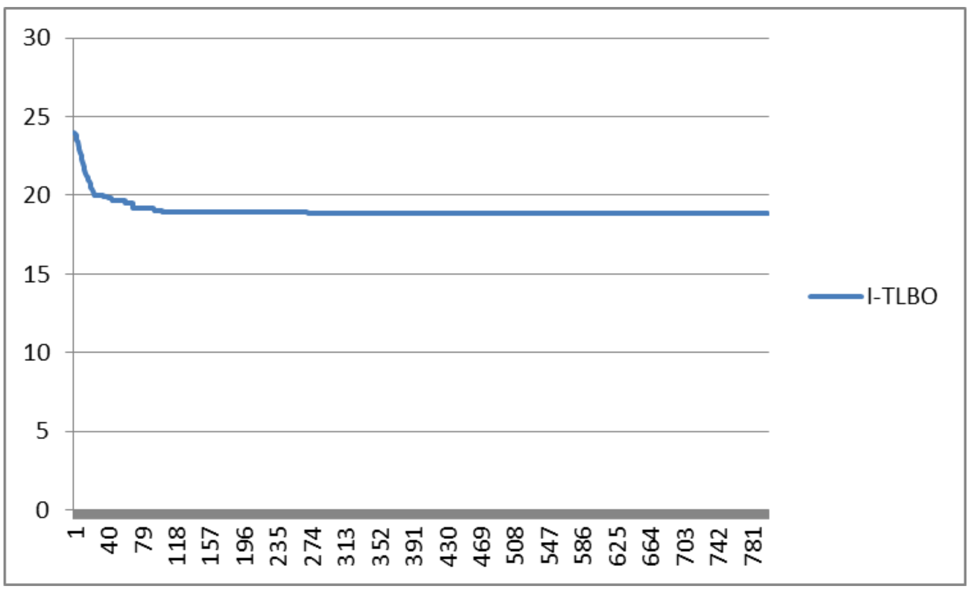

Fig. 1- Variation of best value of objective function with number of generations for I-TLBO techniques.