An Innovative Self-Adaptive Multi-Population Jaya Algorithm based Technique for Evaluation and Improvement of Reliability Indices of Electrical Power Distribution System

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***Abstract*—** An innovative Self-Adaptive multi-population Jaya algorithm based methodology is developed for optimum modifications for failure rate and repair time for a power 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. The results obtained by the proposed method have been compared with results obtained with other methods mentioned in the literature. The algorithm has been implemented on a sample radial distribution system.

Keywords- *Failure rate, Repair time, Power distribution system, Penalty cost function, Self-Adaptive multi-population based Jaya algorithm.*

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I. Introduction

Reliability evaluation of power distribution systems is important from consumer's view-point. The power available to the customers should be reliable and clean in nature. For monitoring the reliability aspects of the power system different indices are essential to determine. 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]. Arya et al. [22] proposed an innovative methodology for evaluation of Reliability indices accounting omission of random repair time for distribution systems using Monte Carlo simulation. Tiwary et al. [23] proposed a method for determination of Optimum period between Inspections for Distribution system based on Availability Accounting Uncertainties in Inspection Time and Repair Time. Tiwary et al. [24] described a Teaching Learning based Optimization method for Inspection repair availability optimization of the distribution system.

The paper describes an algorithm for reliability improvement of distribution system accounting constraints on energy based and customer oriented indices using Self-Adaptive multi-population based Jaya algorithm (SAMP-Jaya). The method proposed is based on Self-Adaptive multi-population based Jaya algorithm is implemented on radial distribution system. Statistical analysis is also provided.

II. 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)

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

Customer average interruption duration index (CAIDI)

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

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.

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

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

III. PROBLEM FORMULATION

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

$$J = J_1 + J_2 \qquad (1)$$

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

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

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

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

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

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

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

$$\text{SAIFI} \leq \text{SAIFI}_d$$

$$\text{SAIDI} \leq \text{SAIDI}_d$$

$$\text{CAIDI} \leq \text{CAIDI}_d$$

$$\text{AENS} \leq \text{AENS}_d$$

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

IV. OVERVIEW OF SELF-ADAPTIVE MULTI-POPULATION BASED JAYA ALGORITHM (SAMP-JAYA):

The self-adaptive multi-population based Jaya algorithm for solving the constrained and unconstrained numerical and engineering optimization problem was proposed by Rao et al. [27]. It is based on the concept that the solution obtained for a given problem should move towards the best solution and avoid the worst solution. First, the initial population is generated having population size (NP) and number of design variables (D) is decided. Now divide the total population into m sub populations depending on quality of solution. Identify the best and worst solution in each and every sub population.

Obtain the new value as follows:

$$Y_i' = Y_i + rand_1(Y_{best,i} - |Y_i|) - rand_2(Y_{worst,i} - |Y_i|) \qquad \ldots\ldots\ldots(5)$$

Where

Y_i is previous value

$Y_{best,i}$ is best solution

$Y_{worst,i}$ is worst solution

$rand_1, rand_2$ are random numbers having range of [0,1]

Accept the better solution in each sub population. Merge the entire sub population together. Now check if previous best solution of entire population is better than the current best solution in the entire population. If yes, then m is decreased by 1, else m is increased by 1. The procedure is terminated if a maximum number of generations have been executed.

V. RESULTS AND DISCUSSIONS

The SAMP-Jaya 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 SAMP-Jaya, I-TLBO [26], TLBO [25], PSO [21] and CAPSO [21] based on 30 numbers of runs. Fig.-1 shows the evolution of best fitness value (objective function) as obtained by SAMP-Jaya algorithm. Table 2 shows the optimized set of decision variables along with least values of objective function as obtained by SAMP-Jaya. 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.

VI. 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 SAMP-Jaya to obtain optimum failure rate and repair times so as to achieve desired levels of the indices. SAMP-Jaya based method has given better results than in comparison to proposed methods in the literature. 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 SAMP-Jaya, I-TLBO, TLBO, PSO and CAPSO based on 30 numbers of runs.

Statistics	Technique				
	SAMP-Jaya	I-TLBO [26]	TLBO [25]	CAPSO [21]	PSO [21]
Average value of best fitness function values	18.6023	18.6589	18.7134	19.0522	19.2545
Standard deviation	0.0135	0.0147	0.0165	0.0252	0.1445
Minimum value of best fitness function	18.0949	18.1845	18.3254	19.0214	19.0738
Maximum value of best fitness function	18.5247	18.7899	18.9234	19.1230	19.5737

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

Variables	Magnitudes as obtained by					
	SAMP- Jaya	I-TLBO [26]	TLBO [25]	PSO [21]	CAPSO [21]	DFP [21]
1	0.2309	0.2312	0.2337	0.2395	0.2387	0.2401
2	0.0910	0.0915	0.0933	0.0991	0.0973	0.0948
3	0.1933	0.1935	0.1950	0.2065	0.2005	0.2001
4	0.1765	0.1768	0.1783	0.1831	0.1839	0.1830
5	0.1911	0.1916	0.1925	0.1956	0.1977	0.1982
6	0.0972	0.0982	0.0997	0.1000	0.1000	0.0999
7	0.0973	0.0974	0.0996	0.0999	0.1000	0.0989
r1	6.9024	6.9034	6.9041	6.9454	6.9291	6.8941
r2	7.7225	7.7237	7.7254	7.9565	7.7865	7.9261
r3	8.1334	8.1345	8.1358	7.7388	8.1588	8.2660
r4	11.4022	11.4038	11.4050	11.5192	11.7020	11.8820
r5	11.1443	11.1467	11.1483	11.3236	11.6383	11.2861
r6	7.9813	7.9835	7.9856	8.0000	7.9996	7.9757
r7	11.9812	11.9832	11.9857	12.0000	11.9931	11.9024
Objective function, J	18.3586	18.3634	18.8914	19.0738	19.0214	19.1054

Table 3- Current and optimized reliability indices.

S. No.	Index	Current values	Optimized values						Threshold values
			SAMP-Jaya	I-TLBO [26]	TLBO [25]	PSO [21]	CAPSO [21]	DFP [21]	
1	SAIFI interruptions/ customer	0.7200	0.4065	0.4078	0.4102	0.4150	0.4130	0.4127	0.5000
2	SAIDI hrs/ customer	8.4500	3.3000	3.3001	3.3003	3.3056	3.3022	3.2991	4.0000
3	CAIDI hrs/ customer interruption	11.7361	7.9247	7.9267	7.9967	7.9657	7.9955	7.9933	8.0000
4	AENS kWh/ customer	26.4100	10.000	10.000	10.000	10.000	10.000	9.9968	10.000

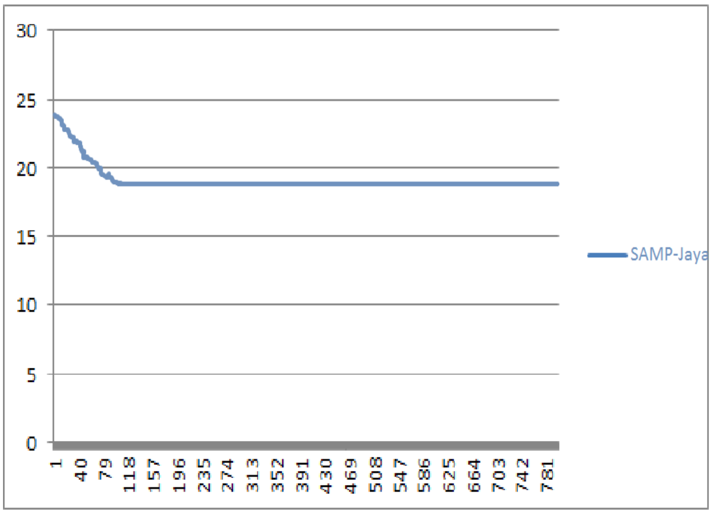

Fig. 1- Variation of best value of objective function with number of generations for SAMP-Jaya techniques.