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Distributed System Reconfiguration with Optimal Allocation of DFACTS and DG for Reliability Enhancement using DTLBO Algorithm

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Abstract: *Reconfiguration is an important activity to increase the efficiency of the power distribution systems. The reconfiguration problem is normally addressed as complicated combinatorial optimization problem due to the presence of discrete decision variables within it. Discrete Teaching-Learning Based Optimization (DTLBO) algorithm is proposed to solve such problem. In this work, the distributed system reconfiguration is to be done along with simultaneous placement of Distribution Flexible AC Transmission System device (DFACTS) and Distributed Generations (DG) in order to improve the reliability of the system. This is to be achieved by ensuring the load balance, voltage profile and reduced system losses. The objective of this proposed work is to minimize the reliability indices. The system variables are to be optimized with the above objective by using the DTLBO algorithm. The proposed approach is to be tested in IEEE 33 and 69-bus radial distribution systems.*

Keyword: *DFACTS; Distributed Generation; DTLBO Algorithm; Reconfiguration; Reliability indices.*

1. INTRODUCTION

The distribution system is an important part of the total electric system, as it provides the final link between the bulk system and the customer. In many cases, these links are radial in nature and therefore susceptible to outage due to a single event. It has been stated that 80% of all interruptions occur due to failures in the distribution system. These outages usually result in customer interruptions which are relatively local in nature and have quite different effects to disturbances in the bulk power network. Distribution system re1iability evaluation therefore consists of assessing how adequately the different parts are able to perform their intended function.

Power system has been providing on a reliable and economic supply of electrical energy to their customers. Additional capacities of generation and network facilities are inbuilt in order to ensure continuous supply in the event of failures, forced outages of plant and regular scheduled maintenance. Renewable energy resources effectively provide the support as distributed generations. The distributed generation energy resources including Photovoltaic (PV) array, small wind turbine, fuel cell etc., are playing an important role in reduction in power loss, improving the reliability of the system. DFACTS devices are used in distribution systems for improving the power quality.

Distribution Static Synchronous Compensator (DSTATCOM) is used to mitigate the problems of power quality such as reactive power compensation, power factor and harmonics distortion. Distribution system reconfiguration is a process which optimizes the operation of distribution system with different goals. The reconfiguration has great impact on the reliability improvement.

2. LITERATURE REVIEW

In the competitive environment utilities must have accurate information about the system performance to ensure that the customers' expectations are met. The electric utility industry has developed several performance measures of reliability to evaluate the system performance. In this work, customer oriented indices System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration

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Index (CAIDI), Customer Average Interruption Frequency Index (CAIFI) and load oriented index Average Energy Not Supplied(AENS) are to be calculated [1]. One of the significant methods for reliability enhancement is reconfiguration of distribution network. Reconfiguration is modifying the structure of the distribution system by changing the switches between the feeders. The impact of reconfiguration on loss reduction, load balancing, voltage profile, and reliability of the network are discussed [2-4]. A reconfiguration technique presented for reliability improvement of the radial network in that they investigated only the SAIFI, AENS, total active power loss and total network cost based on the Self-Adaptive Modified Optimization algorithm [5]. In this work, along with the above mentioned SAIFI & AENS, the SAIDI, CAIDI and CAIFI are also to be considered using DTLBO algorithm.

In the distributed power system, the benefits of DGs are based on their optimal location and size. The technical benefits of DGs also include the loss minimization, stability improvement and reliability enhancement of the system. Harmony Search Algorithm (HSA) with differential operator is proposed to install multiple DG units optimally in distribution system [6]. In which the method has many parameters to regulate and uses more memory than DTLBO. The Discrete Particle Swarm Optimization technique to select optimal locations and sizes of PV array and wind turbines along with capacitor banks [7]. In DPSO, the actual optimization variable value is round-off to the nearest integer value during the iterations and is converged to the near optimal solution but the DTLBO converges to the global optimum solution. Teaching-Learning Based Optimization (TLBO) algorithm is proposed for the optimization of cost function and implemented for the placement of 2, 3 and 4 generators in an IEEE 14-bus distribution system [8].

Among the many FACTS devices DSTATCOM provide the efficient reactive power compensation in the distribution network. DSTATCOM is used to mitigate the problems of power quality [9]. It is a custom power device which is installed in parallel with distribution system. Firefly Algorithm (FA) is proposed for optimal placement of the DSTATCOM in distribution system for the power quality enhancement [10]. In this work the optimal placement of DSTATCOM is to be investigated for the improvement of reliability in presence of DG using DTLBO algorithm. Radial distribution network power flow is prime importance for the effective planning of load transfer. One of the effective methods for the load flow analysis is forward and backward sweep method [11].

Several optimization algorithms are proposed for the simultaneous reconfiguration and optimal allocation of DG or DFACTS unit in distribution system. However, simultaneous reconfiguration with both DG and DFACT is rarely available in the literature. A Fuzzy-Ant Colony Optimization algorithm is proposed for Simultaneous reconfiguration and allocation of DFACTS and DG [12].

In that Ant Colony Optimization (ACO) approach has been used for simultaneous multi-objective reconfiguration and optimal allocation of PV array and DSTATCOM in a distribution network. The input and output data are normalized in the same range based on fuzzy sets in order to avoid the convergence problem. DTLBO algorithm is easily converged to the global optimum. TLBO algorithm [13] is a metaheuristic optimization algorithm based on the population and this is a continuous space optimization algorithm, but reconfiguration is a complicated optimization problem with discrete decision variables. A new metaheuristic DTLBO algorithm which effectively solves the distribution system reconfiguration problem in discrete space [14]. This algorithm has no control parameters. Fast converged and easily adapted for the different distribution systems.

This paper concentrates the distribution system reconfiguration along with simultaneous allocation of DFACTS and DG using DTLBO algorithm. First the problem is to be formulated as an optimization problem with the objective of minimization of reliability indices with respect to various constraints in order to determine the optimal configuration of distribution network.

3. PROBLEM FORMULATION

Reliability of service has always been of prime importance to electric utility systems. In general, the basic activities associated with reliability assessment can be divided into the two fundamental segments of measuring past performance and predicting future performance. Reliability is primarily concerned with frequency of interruption faced by customers. Reliability indices are classified as customer oriented indices and load and energy oriented indices. When the reliability indices are near to zero, then the reliability of the system is high.

The objective functions are minimization of the reliability index SAIFI, SAIDI, CAIFI, CAIDI and AENS,

$$minimize\ f_i(x) = \sum_{i=1}^{5} W_i * g_i(x) \qquad (1)$$

Constraints,

$$V_{k,min} \le V_k^{'} \le V_{k,max}$$

$$I_{k,k+1}^{'} \le I_{k,k+1\ max}$$

$$\sum_{k=1}^{ns} P_{PV,k} + P_{DSTATCOM,k} \le \sum_{k=1}^{ns} P_k + P_{loss,k}$$

Where the $g_i(x)$ represents the reliability indices,

System Average Interruption Frequency Index:

SAIFI gives information about the average frequency of sustained interruptions of customers connected with the distribution network. It is estimated by dividing the accumulated number of customer-interruptions in a year by the number of customers served.

$$SAIFI = \frac{total\ no.of\ customers\ \ interrupted}{total\ \ no.of\ customers\ \ served} = \frac{\sum \gamma_i N_i}{\sum N_i} \quad (2)$$

Customer Average Interruption Frequency Index:

The value of CAIFI is very useful in recognizing chronological trends in the reliability of a particular distribution system. In the application of this index, the customers affected should be counted only once, regardless of the number of interruptions they may have experienced in the year.

$$CAIFI = \frac{total\ \ no.of\ customers\ \ interrupted}{total\ \ no.of\ customers\ \ affected} = \frac{\sum \gamma_i N_i}{\sum N_a} \quad (3)$$

System Average Interruption Duration Index:

This index is defined as the average interruption duration for customers served during a year. It is determined by dividing the sum of all customer sustained interruption durations during the year by the number of customers served during the year.

$$SAIDI = \frac{total\ no.of\ customers\ interrupted\ duration}{total\ no.of\ customer\ served} = \frac{\sum U_i N_i}{\sum N_i} \quad (4)$$

Customer Average Interruption Duration Index:

This index is defined as the interruption duration for customers interrupted during a year. It is determined by dividing the sum of all customer sustained interruption durations during the specified period by the number of sustained customer interruptions during the year.

$$CAIDI = \frac{total\ \ no.of\ customer\ s\ interruped}{total\ \ no.of\ interrupted\ \ duration} = \frac{\sum \gamma_i N_i}{\sum U_i N_i} \quad (5)$$

Energy Not Supplied (ENS):

$$ENS = total\ energy\ not\ supplied\ by\ system = \sum L_{a,i} U_i \quad (6)$$

Average Energy Not Supplied (AENS):

This index is also known as Average System Curtailment Index (ASCI).

$$AENS = \frac{total\ \ energy\ \ not\ \ supplied\ \ (ENS)}{total\ \ no.of\ \ customers} = \frac{\sum L_{a,i} U_i}{\sum N_i} \quad (7)$$

The three basic reliability parameters are average failure rate γ_i, average outage time r_i, average annual outage time U_i,

$$\gamma_i = \sum_{j\epsilon N} \gamma_{e,j} \quad (8)$$

$$U_i = \sum_{j\epsilon N} \gamma_{e,j}\ r_{ij} \quad (9)$$

$$r_i = \frac{U_i}{\gamma_i} \quad (10)$$

3.1 PV Array

Distributed generation is the key factor to improve the reliability of the system. Here a PV array is selected as the DG. A PV array is a series-parallel combination of PV panels. A PV system for residential, commercial, or industrial energy supply normally contains PV array, dc–dc converter, inverter, and a tracking system. The active and reactive powers of PV unit can be calculated using the following equations,

$$P_{pv} = \Big[\frac{V_k^2}{R_k} P_{pv,loss} - (P_k^2 + Q_k^2) - -Qpv22PkPpv-2QkQpvGL12 \quad (11)$$

$$Q_{pv} = \Big[\frac{V_k^2}{R_k} P_{pv,loss} - (P_k^2 + Q_k^2) - \big(P_{pv}^2 - 2PkPpv-2QkQpvGL12 \quad (12)$$

3.2 DSTATCOM

The DSTATCOM is one of the DFACTS devices which provide the efficient reactive power compensation in the distribution network. Those basically consist of a coupling transformer with a leakage reactance, a GTO/IGBT Voltage Source Convertor (VSC), and a dc capacitor. DSTATCOM connected parallel with distribution bus through the coupled transformer. The active and reactive powers of DSTATCOM can be calculated using the following equations,

$$P_{dstatcom} = (V_k V_m / X_l) \sin\delta \quad (13)$$

$$Q_{dstatcom} = (V_k^2 / X_l) - (V_k V_m / X_l) \cos\delta \quad (14)$$

4. SOLUTION METHODOLOGY

Reconfiguration is an important activity to increase the efficiency of the power distribution systems. The problem of reconfiguration is normally addressed as complicated combinatorial optimization problem due to the presence of discrete decision variables within it. Conventional methods computed the reconfiguration problem in continuous space. One of the most recently developed metaheuristics is Discrete Teaching-Learning-Based Optimization (DTLBO) Algorithm. The original TLBO is a continuous optimization algorithm, but DTLBO is a discrete optimization algorithm which effectively solves the distribution system reconfiguration in discrete space. This method has not

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any control parameter and is very effective. This is fast converge to global optimal solution and is easily adapted to different distribution systems.

Assume $D = [K_1 K_2 \ldots\ldots K_N]$ where D is the discrete search space of problem and N is the number of elements of it. Also assume $C = [0, 1]$ where C is a closed interval between 0 and 1. The proposed method is formulated as follows,

$$\alpha = 1 + N \times C \tag{15}$$

$$\beta = \min([\alpha], N) \tag{16}$$

In the above equations, α is a mapping from $C = [0, 1]$ to $[1, N + 1]$, and β is mapping from [1, N+1] to [1 2 3…N]. Now for the i^{th} member in c, a member is assigned in D as follows:

$$D(i)_{C(i)} = K_\beta \tag{17}$$

The following steps are involved to enhance the reliability of system by reconfiguration with optimal allocation of PV array and DSTATCOM using DTLBO algorithm.

Step1: Read the system input data and termination condition.
Step 2: Run the power flow. Calculate the objective function and solution vector. Solution vector contains tie switches, size and location of PV array and DSTATCOM.
Step 3: Check configurations using DTLBO algorithm. If configuration is radial, run power flow for it and calculate corresponding objective function. If configuration is not radial, a large no. is considered as corresponding objective function.
Step 4: Update the population using DTLBO
Step 5: As step 3, check configuration and calculate the corresponding objective function.
Step 6: If the new solution is better than existing solutions modify the solution otherwise keep that solution.
Step 7: Based on the best solution obtain the objective function until termination condition reached.
Step 8: Obtain tie switch position, optimal location and size of PV array and DSTATCOM and calculate the objective function.
Step 9: Print the result.

5. RESULTS AND DISCUSSION

Reliability indices calculations require three parameters failure rate, outage time and annual outage time. Failure rate related to length of the line. Assume failure rate of line 0.1 f/yr. and circuit breaker failure rate 0.006 f/yr. Let as assume all conductors are aluminium alloy which have the resistance 0.55Ω/km and reactance 0.351Ω/km. Repair time of the line and circuit breaker is 5 and 2 hours respectively. The Figure 1 and 3 shows the IEEE 33 and IEEE 69 bus system with tie switches respectively. The test systems are validated in five cases,

1. Base case.
2. Reconfiguration alone.
3. Reconfiguration with allocation of PV array.
4. Reconfiguration with allocation of DSTATCOM.
5. Reconfiguration with allocation of PV array and DSTATCOM

5.1 IEEE 33 Bus System

The Table I. Show the results obtained forIEEE 33 bus system. In base case (system without any changes) tie switches 33, 34, 35, 36 and 37 were opened. The system reliability indices SAIFI, SAIDI, CAIFI, CAIDI and AENS were 0.7948, 3.8493, 1.7627, 0.2065 and 8.8445 respectively. It shows that without any changes the system has poor reliability. To improve the reliability, this system is validated with different cases. Each case yields better results than before cases. In the last case, PV array size of 0.6891 MVA and DSTATCOM size of 0.7836 MVA installed on buses 15 and 10 respectively, the tie switches 19, 9, 21, 30 and 25 were reconfigured.

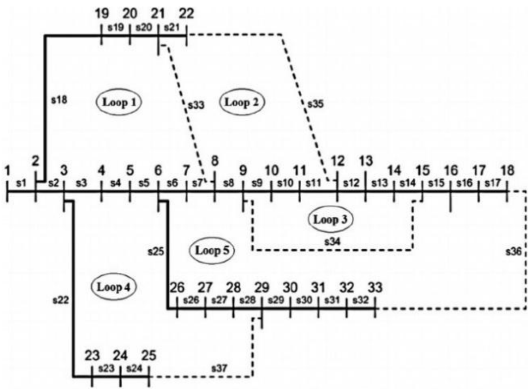

Figure 1 Single line diagram of IEEE 33 bus system

The system reliability indices SAIFI, SAIDI, CAIFI, CAIDI and AENS were reduced to 0.3526, 0.9976, 0.7820, 0.3534 and 0.3455 respectively. Compared with the other cases the allocation of PV array and DSTATCOM along with reconfiguration gives the best reliability improvement. It proves the

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TABLE I RELIABILITY INDICES FOR IEEE 33 BUS SYSTEM

Cases		Case 1	Case 2	Case 3	Case 4	Case 5
Tie switches		33,34,35,36,37	5,12,21,22,32	5,9,13,17,23	3,9,13,17,24	9,19,21,25,30
PV array	Location	-	-	18	-	15
	Size MVA	-	-	0.9714	-	0.6891
DSTATCOM	Location	-	-	-	26	10
	Size MVA	-	-	-	0.7978	0.7836
SAIFI f/ cus. Yr		0.7948	0.5512	0.3688	0.3558	0.3526
SAIDI hr/ cus. Yr		3.8493	0.1772	1.0302	0.9338	0.9976
CAIFI f/ hr		1.7627	1.2223	0.8179	0.7890	0.7820
CAIDI hr/ cus. Yr		0.2065	3.1110	0.3580	0.3810	0.3534
AENS KW hr/ cus.hr		8.8445	0.9566	0.6089	0.9289	0.3455

TABLE II RELIABILITY INDICES FOR IEEE 69 BUS SYSTEM

Cases		Case 1	Case 2	Case 3	Case 4	Case 5
Tie switches		69,70,71,72,73	3,18,43,49,59	6,14,43,53,63	6,18,43,48,59	5,20, 43,47,59
PV array	Location	-	-	4	-	38
	Size MVA	-	-	0.9293	-	1.1365
DSTATCOM	Location	-	-	-	39	29
	Size MVA	-	-	-	1.0885	0.1085
SAIFI f/ cus. Yr		0.4998	0.8770	0.3731	0.3357	0.2894
SAIDI hr/ cus. Yr		2.3228	0.5250	0.5619	0.5374	0.5271
CAIFI f/ hr		4.5277	7.9530	3.3835	3.0444	2.6242
CAIDI hr/ cus. Yr		0.2154	1.6703	0.6640	0.6247	0.5490
AENS KW hr/ cus.hr		3.9372	0.0394	0.0806	0.0578	0.0394

effectiveness of the presented algorithm. Figure 2 shows the improvement of reliability in 33 bus system.

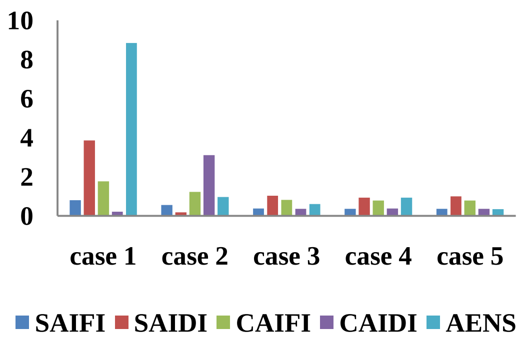

Figure 2 Plot of reliability indices for IEEE 33 bus system

5.2. IEEE 69 Bus System

The test system IEEE 69 bus result shown in Table II. In base case (system without any changes) tie switches 69, 70, 71, 72, and 73 were opened. The system reliability indices SAIFI, SAIDI, CAIFI, CAIDI and AENS were 0.4998, 2.3228, 4.5277, 0.2154 and 3.9372 respectively. Reconfiguration is done in case 2 and PV array size of 0.9293 MVA is installed in 4th bus along with reconfiguration of 6, 14, 43, 53, 63 switches were done in 3rd case. DSTATCOM size of 1.0885 MVA is installed at bus 39 for effective compensation of reactive power along with reconfiguration in 4th case.

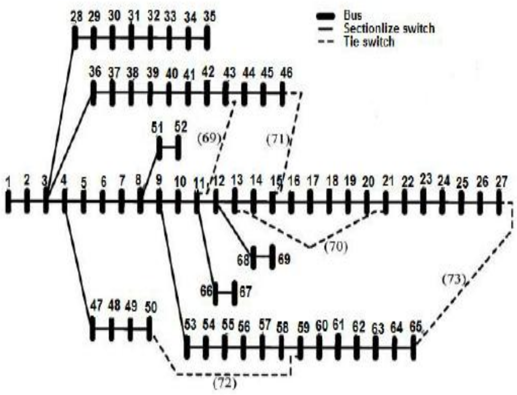

Figure 3 Single line diagram of IEEE 69 bus system

In last case 5, 20, 43, 47, 59 switches are reconfigured and PV array size of 1.1365 MVA, DSTATCOM size of 0.1085 MVA were installed at 38 and 29 respectively. Further the reliability indices are reduced. The system reliability is extremely improved comparing with the other cases. Figure 4 shows the reliability indices decreased significantly in

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last case. It is evident that the proposed approach improves the reliability of the distribution system.

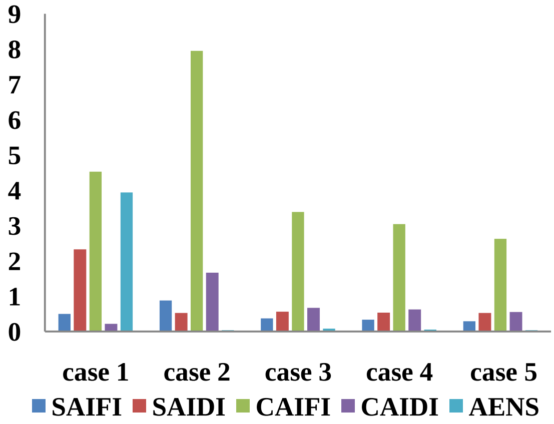

Figure 4 Plot of reliability indices for IEEE 69 bus system

6. CONCLUSION

In this work Discrete Teaching Learning Based Optimization algorithm is used for the IEEE 33 and IEEE 69 bus radial distribution system's reconfiguration with optimal allocation of PV array and DSTATCOM. Compare with the five cases of results such as base case, only reconfiguration, reconfiguration with allocation of PV array, reconfiguration with allocation of DSTATCOM, and the fifth case reconfiguration with allocation of DSTATCOM and PV array gives the better result. The results show that Distribution system reconfiguration has a significant effect on reliability improvement. Also these effects are greater in presence of PV array and DSTATCOM. This proposed idea is well suited for different radial distribution systems. Obviously this approach improves the reliability of the distributed system.

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