OPTIMAL RESTRUCTURING OF DISTORTED DISTRIBUTION SYSTEM BY TEACHING-LEARNING BASED OPTIMIZATION

Dr. K. SURESHKUMAR,
Velammal Engineering College, Chennai, India, sureshbarath@gmail.com

Dr. S. THIRUVENKADAM,
P.A. College of Engineering and Technology, Coimbatore, India, drstv.2011@gmail.com

Abstract: *Distribution Systems are basic connections between utility and utility clients. Distribution system restructuring is a standout amongst the most critical procedures took after for the control of energy loss. Because of the more utilization of non-linear loads by the utility clients, more harmonics are being infused into distribution systems, which may prompt high distortion levels. To lessen the distortion level, power quality constraints are incorporated as one among the other working requirements with the primary goal. The essential goal is to limit the power loss cost of the distribution system while fulfilling the power flow, operational and power quality limitations. This paper proposes Teaching-Learning-Based Optimization (TLBO) to take care of the issue. The backward-forward sweep Harmonic Load Flow (HLF) is utilized to assess the harmonics present in the distribution system, which has been coordinated with TLA. The proposed hybrid TLA-HLF strategy has been validated with IEEE-33 bus distribution and 83-bus Taiwan Power Distribution Company system.*

Key words: *harmonic load flow, power quality, radial distribution system, optimization, teaching-learning algorithm, backward-forward sweep algorithm*

1. Introduction

Distribution System optimal restructuring and optimal capacitor placement are the two widely utilized practices for decrease of aggregate yearly working expense of the distribution system for a long time. Previous strategy is the way toward changing the open/close status of the switches exhibit in distribution system. Later technique diminishes yearly working expense with consideration of capacitor banks in the distinguished ideal areas [10, 13, 21]. In the distorted distribution system, the consideration of capacitors may advance outcome to increment in distortion level [4]. In this way, it is perfect to pursue the previous technique for improvement of distorted distribution system.

Distribution System optimal restructuring has been managed in different papers. The paper [7] led the early work on feeder reconfiguration for loss reduction. In [5], a number programming based arrangement technique was characterized for loss decrease and load adjusting. As of late, the rebuilding has been done with more vigorous and heuristic procedures. The heuristic strategy proposed by [12] recoils the inquiry space, subsequently reduces the calculation time.

The paper [16] proposed a heuristic search strategy for feeder reconfiguration. Evolutionary Programming (EP) was utilized for improving distribution system performance by [8, 20]. In [23], fuzzy appropriation of EP has been proposed for reconfiguration. This requires several iterations bringing about extensively high computational time. Fuzzy multi-objective approach [8] was revealed to limit the quantity of tie switch operations in view of the heuristic standards. For each open switch operation, it expands the fuzzy fulfillment target work for getting ideal arrangement.

The author [11] has portrayed a procedure that uses an Optimal Power Flow (OPF) program to decide the affectability of the open switches. It decides the change to be conclusively open consecutively until the point when the system ends up noticeably spiral. The possibility of utilizing the Neural Network for taking care of the distribution system reconfiguration issue for real systems has been examined in [19]. The paper [26] presented a hybrid strategy which coordinates the fuzzy multi-objective programming and the Genetic Algorithm for assurance of the system arrangement in the appropriation system. An effective, two-stage reconfiguration strategy for loss minimization has been introduced in [24]. The effectiveness of this technique is because of the utilization of the loss affectability regarding the impedances of competitor branches. The author [25] proposed another and effective approach that utilizes Plant Growth Simulation Algorithm (PGSA) as ideal means for the system streamlining of power loss minimization. The versatile crossover genetic algorithm has been embraced in [14] to explore the issue of loss reduction by reconfiguration of primary distribution networks with demand variations during a planning horizon. Genetic algorithm with consecutive encoding approach proposed for reconfiguration of distribution system [6]. A technique in light of the branch-and-bound methodology, which utilizes a tree structure and limits to sort out the seeking was proposed by [15].

Large portions of the examination works completed for optimal restructuring expect sinusoidal working conditions. Naturally, the vast majority of the loads utilized by the utility clients are non-linear, for example, fluorescent lighting, customizable speed drives, PCs, TVs, and so on. These loads infuse more harmonics into distribution system, which may prompt high contortion levels. Thus, the bothersome contortion level of the utility will cause greater hardware overheating, weight on gear protection, hardware failure and the interference with communication networks. In this manner, it is more fundamental to incorporate power quality constraints with other constraints considered for optimal restructuring. In [1], Standards, for example, the IEEE-519 are alluded to for rules of operation under harmonic conditions, and for creating and assessing relief measures. The hypothetical, demonstrating and recreation parts of distribution system with proliferation of harmonics have been portrayed by the team on Harmonic modeling and simulation [2-3]. The harmonic flow analysis suitable for balanced and unbalanced distribution system in light of in backward/forward sweep based has been managed in [22].

Moreover, all evolutionary and swarm intelligence based algorithms are probabilistic calculations and require regular controlling parameters, similar to population size and number of generations. Other than normal control parameters, diverse algorithms require their algorithm specific control parameters. For example, (i) GA requires mutation rate and crossover rate, (ii) PSO requires inertia weight, and social and cognitive parameters. It is extremely hard to tune the algorithm-specific parameters. The ill-advised tuning of these parameters prompts increment in computational exertion or potentially yields the local optimal solution. In the majority of the cases, these parameters have been tuned by trial and error, which winds up noticeably tedious process. Considering this reality, as of late, the Teaching-Learning-Based Optimization (TLBO) algorithm [17-18] was proposed, which works absolutely in light of regular controlling parameters and has no algorithm particular parameters. With keeping the upside of TLBO, in this paper, ideal restructuring with the presence of harmonics have been proposed.

2. Problem formulation

The idea of the distribution system optimization issue has been seen as minimization of aggregate yearly power loss cost of the system. The goal is to limit the system total annual power loss while power flow, operational and power quality constraints are met. The objective function of the problem is given in equation (1),

Minimize

$$F_{\text{Total}} = \sum_{i=1}^{nf} F_{\text{Power},i} \tag{1}$$

Where,

F_{Total} =Total Annual operating cost in \$/year

$F_{\text{Power},i}$ =Power Loss cost of the ith feeder in \$/year

nf =Total number of feeders in distribution system

a. *Calculation of Power Loss Cost and Power Flow constraints*

The energy loss cost has been calculated using the power flow. It has been described with the use of simple single feeder distribution system shown in Fig. 1.

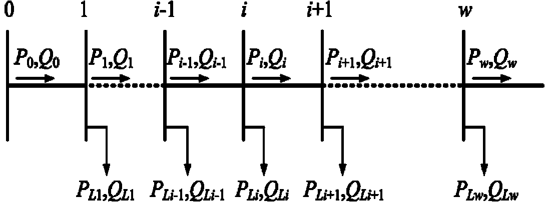

Fig. 1. Single-line diagram of a main feeder

The following set of recursive equations is used to compute power flow,

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1}\frac{P_i^2+Q_i^2}{|V_i|^2} \tag{2}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i,i+1}\frac{P_i^2+Q_i^2}{|V_i|^2} \tag{3}$$

$$V_{i+1}^2 = V_i^2 - 2(R_{i,i+1}\ P_i + X_{i,i+1}\ Q_i) + (R_{i,i+1}^2 + X_{i,i+1}^2)\ \frac{P_i^2 + Q_i^2}{|V_i|^2} \tag{4}$$

The power flow equations with the inclusion of shunt admittance to the system are shown in equations from (5) to (7).

$$P_{i+1} = P_i - P_{Li+1} - \frac{R_{i,i+1}}{|V_i|^2}\ \left\{P_i^2 + (Q_i + Y_{i,i+1}|V_i|^2)^2\right\} \tag{5}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - \frac{X_{i,i+1}}{|V_i|^2}\ \left\{P_i^2 + (Q_i + Y_{i1,i+1}|V_i|^2)^2\right\} - Y_{i1,i+1}|V_i|^2 - Y_{i2,i+1}|V_i|^2 \tag{6}$$

$$|V_{i+1}|^2 = V_i^2 - 2(R_{i,i+1}\ P_i + X_{i,i+1}\ (Q_i + Y_{i,i+1}|V_i|^2)) + (R_{i,i+1}^2 + X_{i,i+1}^2)\ \frac{P_i^2 + (Q_i + Y_{i,i+1}|V_i|^2)^2}{|V_i|^2} \tag{7}$$

where, the radial structure of system must be maintained, and all loads must be served.

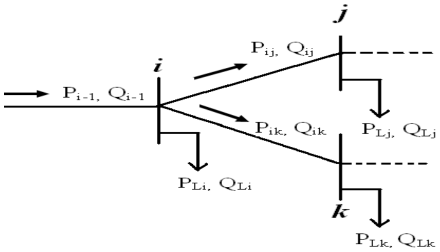

Fig. 2. Single line diagram of a node with two sub laterals

In case of a node with two or more sub feeders as shown in Fig. 2, the load flow equations will reflect bus powers including branch powers as given in equations (8) and (9),

$$P_{i-1} = P_{Li} + P_{ij} + P_{ik} \tag{8}$$

$$Q_{i-1} = Q_{Li} + Q_{ij} + Q_{ik} \tag{9}$$

The apparent power transported by the branch must satisfy the branch current capacity. The voltage magnitude at each bus must be maintained within limits. These power flow constraints are expressed as follows:

$S_j \leq S_{j,max}$ for j ϵ 1 to nl, 'nl' total number of branches (10)

$V_{i,min} \leq V_i \leq V_{i,max}$; for i ϵ 1 to nb, 'nb' total number of buses (11)

$F_{total} = P_{loss} * K_p$; where, P_{loss} is the transmission line loss of the system and K_p is the equivalent annual cost of power loss in \$/(kW-year) assumed as 168 \$/(kW-year)

b. Calculation of Harmonics and Power Quality Constraint

The harmonic component of the total real power loss is calculated by a harmonic power flow algorithm (HPF) by Teng and Chang (2007). The power quality constraint at each bus is to be kept less or equal to the maximum allowable harmonic distortion level as shown in (12),

$$\%\,THD_i \leq \%\,THD_{max} \tag{12}$$

The total harmonic distortion level of bus 'i' is defined by,

$$\%\ THD_i = \frac{\sqrt{\sum_{h=h_0}^{h_{max}} |V_i^{(h)}|^2}}{|V_i^{(1)}|^2} \tag{13}$$

where,

% THD_{max} is maximum allowable harmonic distortion level at each bus

c. *Operational Constraints*

i. Under any configuration, the restructured system must retain the radial structure and there should not be any formation of loops.

ii. All loads must be served and no un-served loads.

3. Teaching-Learning-Based Optimization for Optimal Restrucuring

In distribution system reconfiguration, the switch is typically chosen as the choice variable. It can be allotted either an esteem 0 (zero) or 1, which implies open or close switch individually. The measurement of choice factors is significantly diminished, when independent loops are taken as choice factors described in Wang and Cheng (2008). Nonetheless, it can't stay away from the unfeasible arrangements in the iterative system. The switches are portrayed in four states in order to lessen the odds of unfeasible solution in the iterative method and to additionally enhance the effectiveness of estimation.

i. Open state: a switch is open in a feasible solution

ii. Closed state: a switch is closed in a feasible solution

iii. Permanent closed state: a switch is closed in all feasible solutions

iv. Temporary closed state: switches that have been considered in the earlier loop should be treated as closed switch for the loop under considerations.

After the delineation of the conditions of all switches, the permanently closed switches can be wiped out from the conceivable arrangement sets of the choice factors. Also briefly shut switches can be fiscally erased. At that point the aggregate number of switches introduces in each loops is computed and connected as state factors for TLBO algorithm.

The choice of number of courses offered for TLBO is the same as number of loops display in the distribution system. The real power loss, %THD, branch currents and bus voltages relating to separate setup is figured utilizing outspread load stream and harmonic load stream. The Pseudo code of the proposed calculation has been depicted beneath,

---

```
Set Maximal iteration number (MAXIT), Number of Courses Offered (V), Number of learners (P), generation=0

// Initial Population
G(P,V)=random()
// Find the mean for all the courses offered by the learners of generation
Mean (V) = f(V,P)

// Calculate the fitness value for all population
Obj(G(P))

//Execute the following steps for fixed number of iterations (MAXIT) till (generation< MAXIT )
{
//Find the best individual of the generation and becomes the teacher
Vbest,generation=Minimum(Obj(G(P))
//Find the best individual population
Gbest=f(Vbest,generation)

//Evaluate the teaching factor
tf=(1+Math.random()*(2-1))

//Produce the improved learners and produce the teachers
Gteacher(P,V)=
G(P,V)+(Math.random()*(G(Gbest, V)-tf*Mean(V))

//find the best population and prepare the set of learners
if(Obj(G(P))>Obj(Gteacher(P)))
Glearners(P,V) =Gteacher(P,V)
Else
Glearners(P,V) =G(P,V)

//Interaction phase of the learners,  i and j refers integers (< V) and i≠j
if(Obj(Glearners(P,i))>Obj(Glearners(P,j)))
G(P,V)=Glearners(P,i)+
Math.random()*(Glearners(P,i)- Glearners(P,j))
Else
G(P,V)=Glearners(P,i)+
Math.random()*(Glearners(P,j)- Glearners(P,i))

//increment the generation count
generation =generation+1;
}
```

---

3. Simulation Results

The effectiveness of the algorithm has been approved through two test distribution systems; Test Case 1 and Test Case 2 as depicted in Wang and Cheng (2008). For this situation, optimal restructuring was done by considering both the systems working under ordinary conditions, i.e., all the branches are being stacked without disregarding its points of confinement, voltage at the bus is inside utmost and the phases are balanced.

1. Test Case 1

The proposed algorithm has been tried on 33 bus radial distribution systems, which has 5 ordinarily opened switches, 32 typically closed switches and it is expected as balanced three-phase with 12.66kV. The relating power loss is 202.7kW. For the distorted voltage, harmonic creating loads, to be specific fluorescent lighting, Adjustable Speed Drives (ASD), and non-particular sources, for example, PCs, TVs, and so on, were considered. A total portrayal of the system harmonic can be found in Abdelsalam et al (2010). The ordinary spectrum of these nonlinear loads is given in Table 1.

Table 1

Harmonic Current Magnitudes as % of Fundamental and Phase Angles with respect to voltage

Harmonic Order	Adjustable Speed Drives (ASD)		Fluorescent Lighting (FL)		Non-specific Sources (NS)	
	Magitude in %	Angle in degrees	Magitude in %	Angle in degrees	Magitude in %	Angle in degrees
1	100	-1.45	100	-107	0	0
3	84.6	-8.34	19.2	76	0	0
5	68.3	-14.23	10.7	10	0	0
7	47.8	-20.13	2.1	37	100	105.5
9	27.7	-29.02	1.4	31	3.6	-44.4
11	0.2	-27.91	0.9	36	3.2	139.4
13	6.1	158.2	0.6	47	0	0
15	4.2	122.3	0.5	20	0	0

All loads were dealt with as consistent PQ spot loads for consonant examinations for the 33 bus radial distribution system. Load composition as far as consonant sources is given in Table 2. After the effective execution of radial and harmonic load flow, the initial arrangement harmonic voltages with %THD has been appeared in Table 3. From the Table 3, it is watched that for the buses 18, 19, 20, 30, 31 and 32, %THD surpasses 3%.

Table 2

33-bus RDS Load composition in terms of harmonic sources

Bus No.	P in MW	Q in MVAR	% ASD	% FL	% NS	Bus No.	P in MW	Q in MVAR	% ASD	% FL	% NS
1	0.1	0.06	25	10	65	17	0.09	0.04	10	20	70
2	0.09	0.04	20	10	70	18	0.09	0.04	10	10	80
3	0.12	0.08	15	15	70	19	0.09	0.04	20	30	50
4	0.06	0.03	10	20	70	20	0.09	0.04	10	20	70
5	0.06	0.02	10	10	80	21	0.09	0.04	10	10	80
6	0.2	0.1	20	30	50	22	0.09	0.05	10	20	70
7	0.2	0.1	10	10	80	23	0.42	0.2	20	30	50
8	0.06	0.02	20	30	50	24	0.42	0.2	10	10	80
9	0.06	0.02	20	30	50	25	0.06	0.025	10	20	70
10	0.045	0.03	10	20	70	26	0.06	0.025	10	10	80
11	0.06	0.035	10	20	70	27	0.06	0.02	10	20	70
12	0.06	0.035	20	30	50	28	0.12	0.07	10	20	70
13	0.12	0.08	10	10	80	29	0.2	0.6	20	30	50
14	0.06	0.01	10	20	70	30	0.15	0.07	10	10	80
15	0.06	0.02	10	10	80	31	0.21	0.1	10	20	70
16	0.06	0.02	20	30	50	32	0.06	0.04	15	10	75

For optimal restructuring, the aggregate number of loops introduce in the distribution system is distinguished. In the wake of ordering the switches of each loop as in view of close, open, permanently closed and temporary closed as portrayed in Wang and Cheng (2008), the last arrangement sets are given as,

$$\left.\begin{aligned} L_1 &= \{S_4, S_5, S_6, S_7, S_{20}, S_{19}, S_{33}\} \\ L_2 &= \{S_8, S_9, S_{10}, S_{11}, S_{21}, S_{35}\} \\ L_3 &= \{S_{12}, S_{13}, S_{14}, S_{34}\} \\ L_4 &= \{S_{25}, S_{26}, S_{27}, S_{28}, S_{23}, S_{24}, S_{37}\} \\ L_5 &= \{S_{15}, S_{16}, S_{17}, S_{32}, S_{31}, S_{30}, S_{29}, S_{36}\} \end{aligned}\right\} \quad (14)$$

From the above condition (14), obviously the Test case I has five loops (L_1, L_2, L_3, L_4 and L_5) and these loops have 7,6,4,7 and 8 number of switches respectively. The TLBO algorithm has been proposed to recognize the best arrangement of open switches. According to TLBO, the quantity of courses offered is considered as five (ie. the quantity of loops). For example for the considered course L1, if the esteem produced in any population is 3 then S6 is the switch to be opened in loop1 and the similar procedure is preceded for whatever is left of the courses for the population. The initial population and their individual losses were computed and stored. The generation size (P) and maximum iteration number (MAXIT) are assumed as 20 and 50 separately. Considering condition (1) as the goal for TLBO, after the effective execution, the power loss cost is diminished. What's more, the branch currents and bus voltages were kept up inside the cutoff and % THD has been decreased essentially contrasted with the initial configuration.

TLBO tunes for the improved restructuring of the distribution system. The proposed strategy lessens the power loss from 202.67kW to 142.16kW, and keeps up the bus voltages well above least esteem. The convergence characteristic for the TLBO algorithm is appeared in Figure 2. Additionally, the % THD of the buses previously, then after the fact restructuring through TLBO algorithm is appeared in Figure 3. From the figures, unambiguously the ideal arrangement is achieved under 25 iterations and %THD is lessened at the buses. The Final configuration bus voltages and branch currents are shown through the Figure 4 and Figure 5 respectively, which evident that no buses are kept under 0.9 pu and branch currents are kept within the limit. The result summary with and without consideration of % THD alongside the principle objective is appeared through the Table 4. From the Table 4, plainly the proposed technique ensures guarantees global optimum and decreases the % THD without trading off the target capacity of the issue.

2. *Test Case 2*

The Test Case 2 is a balanced three-phase system with 11.4 kV. It comprises of 11 feeders, 83 ordinarily closed switches and 13 typically open switches. Its characteristic information are given in Wang and Cheng (2008), and the branch limit is 600A and voltage limits are Vmin=0.9pu and Vmax=1.0 pu. The final solution sets for the 13 loops are distinguished. For TLBO, the courses offered have been considered as 13. Load composition as far as harmonic sources, by referring Table 2, is expected for all the load buses of the test case.

Table 3 Initial Configuration harmonic voltages at the buses of 33-bus RDS

Bus No.	|V(3)|	|V(5)|	|V(7)|	|V(9)|	|V(11)|	|V(13)|	|V(15)|	|V|	% THD
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.5055
1	0.00010	0.00012	0.00072	0.00003	0.00002	0.00001	0.00001	0.9970	0.7190
2	0.00064	0.00081	0.00440	0.00017	0.00011	0.00006	0.00004	0.9829	0.8880
3	0.00089	0.00112	0.00574	0.00025	0.00014	0.00008	0.00006	0.9755	1.1194
4	0.00114	0.00144	0.00713	0.00034	0.00018	0.00011	0.00008	0.9681	1.9298
5	0.00178	0.00225	0.01038	0.00054	0.00025	0.00017	0.00012	0.9497	2.2522
6	0.00186	0.00235	0.01145	0.00055	0.00028	0.00017	0.00012	0.9462	2.5402
7	0.00195	0.00248	0.01224	0.00055	0.00030	0.00018	0.00013	0.9413	2.6221
8	0.00195	0.00251	0.01232	0.00054	0.00030	0.00018	0.00013	0.9351	2.6804
9	0.00195	0.00254	0.01232	0.00054	0.00030	0.00018	0.00014	0.9292	2.6891
10	0.00195	0.00255	0.01232	0.00054	0.00030	0.00019	0.00014	0.9284	2.7215
11	0.00196	0.00257	0.01237	0.00054	0.00030	0.00019	0.00014	0.9269	2.7680
12	0.00195	0.00261	0.01233	0.00054	0.00030	0.00019	0.00014	0.9208	2.7906
13	0.00196	0.00263	0.01232	0.00054	0.00030	0.00019	0.00014	0.9185	0.5055
14	0.00199	0.00267	0.01251	0.00055	0.00031	0.00019	0.00014	0.9171	0.7190
15	0.00204	0.00275	0.01312	0.00057	0.00032	0.00020	0.00015	0.9157	0.8880
16	0.00208	0.00285	0.01360	0.00060	0.00033	0.00020	0.00015	0.9137	1.1194
17	0.00208	0.00287	0.01379	0.00060	0.00034	0.00020	0.00015	0.9131	2.8741
18	0.00009	0.00011	0.00077	0.00003	0.00002	0.00001	0.00001	0.9965	3.1216
19	0.00032	0.00042	0.00318	0.00006	0.00009	0.00003	0.00002	0.9929	3.3411
20	0.00036	0.00048	0.00378	0.00007	0.00010	0.00004	0.00002	0.9922	3.4234
21	0.00041	0.00053	0.00437	0.00007	0.00012	0.00004	0.00003	0.9916	0.5063
22	0.00089	0.00111	0.00639	0.00022	0.00016	0.00008	0.00006	0.9794	0.6073
23	0.00149	0.00185	0.01122	0.00034	0.00029	0.00014	0.00010	0.9727	0.6512
24	0.00172	0.00210	0.01409	0.00036	0.00037	0.00016	0.00011	0.9694	0.7022
25	0.00185	0.00234	0.01063	0.00058	0.00026	0.00017	0.00012	0.9477	0.9669
26	0.00196	0.00248	0.01109	0.00063	0.00027	0.00018	0.00013	0.9452	1.9715
27	0.00254	0.00322	0.01354	0.00087	0.00032	0.00024	0.00017	0.9337	2.8342
28	0.00300	0.00381	0.01546	0.00105	0.00037	0.00028	0.00020	0.9255	2.0176
29	0.00326	0.00414	0.01673	0.00114	0.00040	0.00031	0.00022	0.9220	2.1733
30	0.00325	0.00415	0.01785	0.00118	0.00044	0.00031	0.00022	0.9178	3.1466
31	0.00326	0.00417	0.01824	0.00119	0.00045	0.00031	0.00022	0.9169	4.0949
32	0.00330	0.00420	0.01843	0.00119	0.00046	0.00031	0.00022	0.9166	4.7789

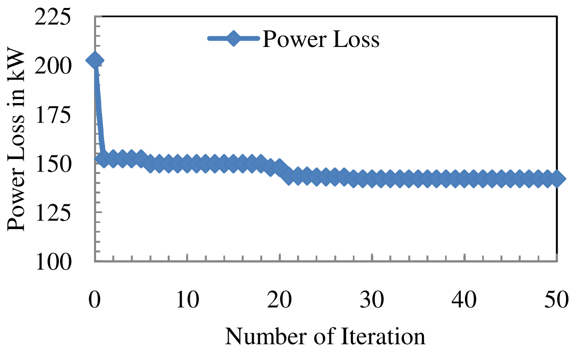

Fig. 2. Convergence characteristic for Test Case 1

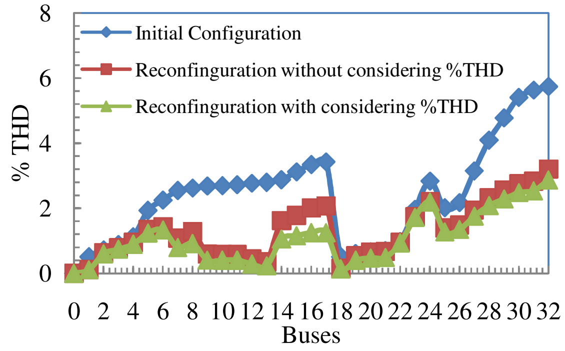

Fig. 3:% THD of the buses for Test Case 1

Table 4

Comparison of results with other methods in literature for Test Case 1

Parameters	Initial Configuration	Optimal Restructuring without considering THD				Optimal Restructuring with considering THD (Proposed Algorithm)
		Goswami and Basu (1992)	Ying-Yi and Saw-Yu (2006)	Wang and Cheng (2008)	Proposed TLBO algorithm	
Power Loss (kW)	202.67	141.6	141.5	139.54	139.54	142.16
Min. bus Voltage (pu)	0.9130	0.9290	0.9342	0.9378	0.9378	0.9335
THD_{max} (%)	4.77	3.67	3.42	3.25	3.25	2.86
Power Loss Cost ($/(KW-yr))	34049.75	23788.8	23772.0	23444.4	23444.4	23956.8
%saving	-	30.13	30.18	31.14	31.14	29.58
Open Switches	-	$S_7,S_9,S_{15}, S_{32},S_{37}$	$S_7,S_{10},S_{14}, S_{36}, S_{37}$	$S_7,S_9,S_{14}, S_{32},S_{37}$	$S_7,S_9,S_{14}, S_{32},S_{37}$	$S_7,S_9,S_{14}, S_{36},S_{37}$
NFE	-	1127	945	783	492	426

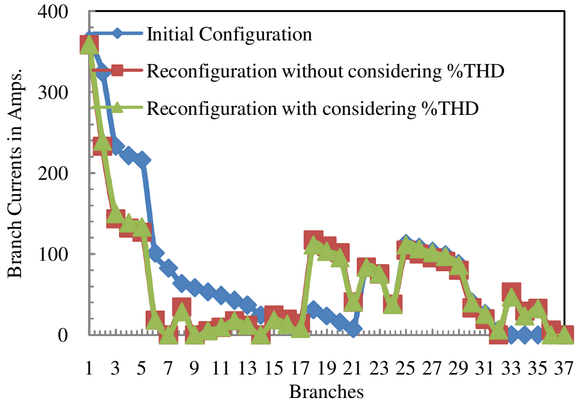

Fig. 5. Final configuration branch currents of Test Case 1

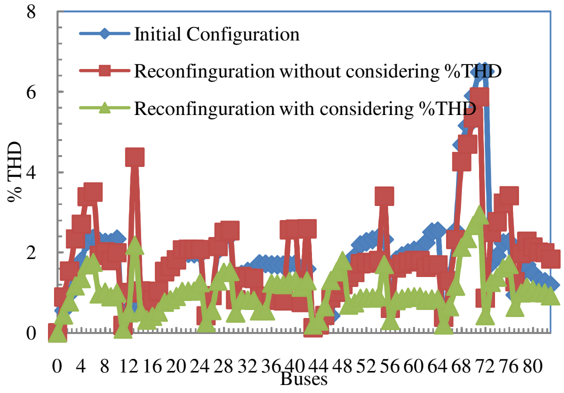

Fig. 6. % THD of the buses for Test Case 2

TLBO recognizes the ideal structure of the distribution system. The proposed technique decreases the power loss from 542.56kW to 472.34kW, and keeps up the bus voltages well above least esteem. The % THD of the buses prior and then afterward rebuilding through TLBO calculation is appeared in Figure 6. From the figure, it is obvious that %THD is diminished at all the buses.

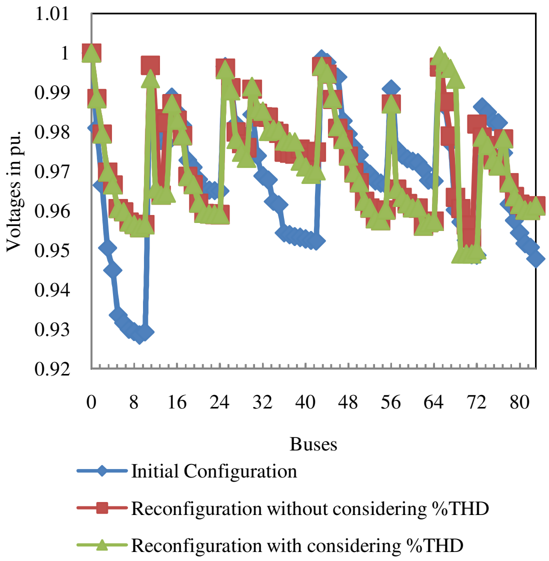

Fig.7. Final configuration bus voltages of Test Case 2

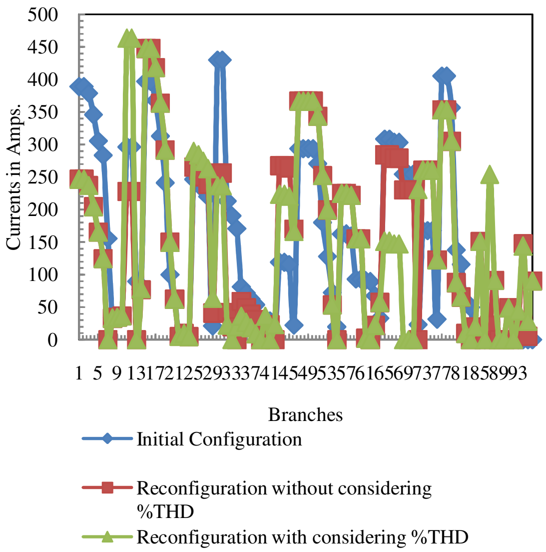

Fig.8. Final configuration branch currents of Test Case 2

The Final configuration bus voltages and branch currents are shown through the Figure 7 and Figure 8 respectively, which evident that no buses are kept under 0.9 pu and branch currents are kept within the limit. The final configuration feeder currents with and without consideration of %THD are shown through the Table 5.

Table 5 Final configuration feeder currents of Test Case 2

Sl. No.	SB	EB	Initial configuration Current in Amps.	Final configuration Current in Amps.	
				Without considering THD	With considering THD
1	0	1	388.73	246.80	246.80
2	0	11	296.18	227.75	463.21
3	0	15	396.78	447.40	447.40
4	0	25	245.99	265.35	289.13
5	0	30	429.59	256.09	236.49
6	0	43	118.89	267.25	223.48
7	0	47	293.23	366.60	366.6
8	0	56	162.16	224.86	224.86
9	0	65	308.37	284.05	151.55
10	0	73	167.67	260.37	260.37
11	0	77	404.90	353.10	353.10

The result summary with and without consideration of % THD alongside the fundamental target is appeared through the Table 6. From the Table 6, obviously the proposed strategy ensures global optimum and decreases the % THD without bargaining the target capacity of the issue.

4. Conclusion

In this paper, TLBO algorithm has been proposed to illuminate restructuring in the presence of harmonics in distribution system. It has been approved with two various types of distribution systems. For both the systems, the proposed algorithm limits the aggregate yearly working expense considering the power stream, operational and power quality requirements. The obtained results were examined in detail. The proposed algorithm has following features,

i. evade from algorithm specific control parameters
ii. ensures global optimum
iii. quick convergence to achieve global optimum and
iv. appropriateness to various sort of distribution system with single as well as different feeders

The result of this work is that the optimal restructuring was completed with presence of harmonics and the proposed TLBO algorithm was more appropriate for this specific streamlining issue. Further, the backward-forward sweep harmonic load flow has been joined with TLBO calculation to diminish the distortion level of the system.

5. Scope for future work

i. This created work can be additionally adjusted/moved up to address unbalanced distribution system improvement.
ii. Optimal rebuilding can be joined with the Capacitor Placement method for facilitate decrease of working expense of the distribution system.

Table 6

Comparison of results with other methods in literature for Test Case 2

Parameters	Initial Configuration	Optimal Restructuring without considering THD				Optimal Restructuring with considering THD (Proposed Algorithm)
		Goswami and Basu (1992)	Ying-Yi and Saw-Yu (2006)	Wang and Cheng (2008)	Proposed TLBO algorithm	
Power Loss (kW)	542.56	469.88	469.88	469.88	469.88	472.34
Min. bus Voltage (pu)	0.9285	0.9536	0.9536	0.9536	0.9536	0.9442
THD_{max} (%)	6.51	5.87	5.87	5.87	5.87	2.94
Power Loss Cost ($/(KW-yr))	91151.39	78939.84	78939.84	78939.84	78939.84	79353.12
%saving	-	13.39	13.39	13.39	13.39	12.94
Open Switches	S_{84}, S_{85}, S_{86}, S_{87}, S_{88}, S_{89}, S_{90}, S_{91}, S_{92}, S_{93}, S_{94}, S_{95}, and S_{96}	S_7, S_{13}, S_{34}, S_{39}, S_{42}, S_{55}, S_{62}, S_{72}, S_{83}, S_{86}, S_{89}, S_{90}, and S_{92}	S_7, S_{13}, S_{34}, S_{39}, S_{42}, S_{55}, S_{62}, S_{72}, S_{83}, S_{86}, S_{89}, S_{90}, and S_{92}	S_7, S_{13}, S_{34}, S_{39}, S_{42}, S_{55}, S_{62}, S_{72}, S_{83}, S_{86}, S_{89}, S_{90}, and S_{92}	S_7, S_{13}, S_{34}, S_{39}, S_{42}, S_{55}, S_{62}, S_{72}, S_{83}, S_{86}, S_{89}, S_{90}, and S_{92}	S_7, S_{13}, S_{33}, S_{39}, S_{41}, S_{55}, S_{62}, S_{69}, S_{83}, S_{86}, S_{89}, S_{90}, and S_{92}
NFE	-	3972	2045	1922	938	1208

References

[1] ”IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems” IEEE Standard 519-1993, IEEE, New York, 1993.

[2] ”Modeling and Simulation of the Propagation of Harmonics in Electric Power Network Part I: Concepts, Models and Simulation Techniques,” Task Force on Harmonics Modeling and Simulation, IEEE Trans. on PWRD, Vol. 11, No. 1, pp. 452-465, Jan. 1996a.

[3] ”Modeling and Simulation of the Propagation of Harmonics in Electric Power Network Part 11: Sample Systems and Examples,” Task Force on Harmonics Modeling and Simulation, IEEE Trans on Power Delivery, Vol. 11, No. 1, pp. 466-474, Jan. 1996b.

[4] Abdelsalam, A., Eajal, and El-Hawary, M. E.: *Optimal Capacitor Placement and Sizing in Unbalanced Distribution Systems With Harmonics Consideration Using Particle Swarm Optimization*, IEEE Transactions on Power Delivery, Vol. 25, No. 3, 2010, p. 1734–1741.

[5] Baran, M.E., and Wu, F.F.: *Network reconfiguration in distribution systems for loss reduction and load balancing*, IEEE Transactions on Power Delivery, Vol. 4, No. 1, 1989, p. 401-1407.

[6] Braz, H. and de Souza B.: *Distribution network reconfiguration using genetic algorithms with sequential encoding: Subtractive and additive approaches*, IEEE Transactions on Power Systems, Vol. 26, No. 2, 2011, p. 582–593.

[7] Civanlar, S., Grainger, J. J., Yin, H., and Lee, S. S. H.: *Distribution feeder reconfiguration for loss reduction*, IEEE Transactions on Power Delivery, Vol. 3, No. 3, 1988, p. 1217–1223.

[8] Das, D: *A fuzzy multiobjective approach for network reconfiguration of distribution systems*, IEEE Transactions on Power Delivery, Vol. 21, No. 1, 2006, p. 202-209.

[9] Delbem, A.C.B., de Carvalho, A.C.Pd.L.F., Bretas, N.G.: *Main chain representation for evolutionary algorithms applied to distribution system reconfiguration*, IEEE Transactions on Power Systems, Vol. 20, No. 1, 2005, p. 425–436.

[10] Farahani, V., Vahidi, B., and Hossein, A.A.: *Reconfiguration and Capacitor Placement Simultaneously for Energy Loss Reduction Based on an Improved Reconfiguration Method,* IEEE Transactions on Power Systems, Vol. 27, No. 2, 2012, p. 587-595.

[11] Gomes, F. V., Carneiro, S., Pereira, J. L. R., Vinagre, M. P., Garcia, P. A. N., De Araujo, L. R.: *A new distribution syst em reconfiguration approa ch using optimum power flow and sensitivity analysis for loss reduction*, IEEE Transactions on Power Systems, Vol. 21, No. 4, 2006, p. 1616-1623.

[12] Goswami, S.K. and Basu, S.K.: *A new algorithm for the reconfiguration of distribution feeders for loss minimization*, IEEE Transactions on Power Delivery, Vol.7, No.3, 1992, pp.1484–1490.

[13] Huang, Y.C., Yang, H.T. and Huang, C.L.: *Solving the Capacitor Placement Problem in a Radial Distribution System Using Tabu Search Approach*, IEEE Transactions on Power Systems, Vol. 11, No. 4, 1996, p. 1868 - 1873.

[14] Leonardo M. O. Queiroz, Christiano Lyra: *Adaptive hybrid genetic algorithm for technical loss reduction in distribution networks under variable demands*, IEEE Transactions on Power Systems, Vol.24, No.1, 2009, p. 445-453.

[15] Lucas S. M. Guedes, Adriano C. Lisboa, Douglas A. G. Vieira, and Rodney R. Saldanha: *A Multiobjective Heuristic for Reconfiguration of the Electrical Radial Network*, IEEE Transactions on Power Delivery, Vol. 28, No. 1, 2013, 311-319.

[16] McDermott, T. E., Drezga, I. Broadwater, R. P.: *A heuristic nonlinear constructive method for distribution system reconfiguration*, IEEE Trans. Power Syst., Vol.14, No.2, 1999, p. 478–483.

[17] Rao, R.V., Savsani, V.J. and Vakharia, D.P.: *Teaching–learning-based optimization: a novel method for constrained mechanical design optimization problems*, Computer Aided Design, Vol. 43, No. 3, 2011, p. 303–315.

[18] Rao, R.V., Savsani, V.J. and Vakharia, D.P.: *Teaching–learning-based optimization: a novel optimization method for continuous non-linear large scale problems*, Information Science, Vol. 183, No. 1, (2011), p. 1–15.

[19] Salazar, H., Gallego, R., Romero, R.: *Artificial neural networks and clustering techniques applied in the reconfiguration of distribution systems*, IEEE Transactions on Power Delivery, Vol.21, No.3, 2006, p.1735-1742.

[20] Song, Y. H., Wang, G. S., Johns, A. T., Wang, P. Y.: *Distribution network reconfiguration for loss reduction using fuzzy controlled evolutionary programming*, In Proceedings of IEE - Generation, Transmission and Distribution, Vol. 144, No. 4, 1997, p. 345–350.

[21] Srinivasas Rao, R., Narasimham, S.V.L., and Ramalingaraju, M.: *Optimal capacitor placement in a radial distribution system using Plant Growth Simulation Algorithm*, Electrical Power and Energy Systems, Vol. 33, 2011, p. 1133–1139.

[22] Teng, J.H., and Chang, C.Y.: *Backward/Forward Sweep-Based Harmonic Analysis Method for Distribution Systems*, IEEE Transactions On Power Delivery, Vol. 22, No. 3, 2007, pp. 1665-1672.

[23] Venkatesh, B and Rakesh Ranjan, *Optimal radial distribution system reconfiguration using fuzzy adaptation of evolutionary programming*, Electrical Power and Energy Systems, Vol. 25, 2003, p.775–780.

[24] Viswanadha Raju, G.K., and Bijwe, P.R., *An Efficient Algorithm for Minium Loss Reconfiguration of Distribution System Based on Sensitivity and Heuristics*, IEEE Transactions on Power Systems, Vol.23, No.3, 2008, p. 1280-1287,

[25] Wang, .C and Cheng, H.Z.: *Optimization of Network configuration in Large distribution systems using plant growth simulation algorithm*, IEEE Transactions on Power Systems, Vol. 23, No. 1, 2008, p. 119-126.

[26] Ying-Yi, H and Saw-Yu, H: *Determination of network configuration considering multiobjective in distribution systems using genetic algorithms*, IEEE Transactions on Power Systems, Vol. 20, No. 2, 2006, p. 1062-1069.