

**INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH
TECHNOLOGY****PERFORMANCE ENHANCEMENT OF RADIAL DISTRIBUTION SYSTEM BY
SIMULTANEOUS RECONFIGURATION, OPTIMAL PLACEMENT OF
DSTATCOM AND PV ARRAY USING DIFFERENTIAL EVOLUTION
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ABSTRACT

This paper presents a performance enhancement of a radial distribution system using simultaneous reconfiguration, optimal placement of DSTATCOM and PV array using differential evolution algorithm (DE). The purpose of this paper is to reduce real power loss, improved voltage profile (VP), increased load balance (LB). Here result proved that simultaneous reconfiguration along with optimal placement of DSTATCOM and PV array is more efficient than Single objective optimization. Also the results obtained from differential evolution algorithm (DE) are more efficient than other method. The test system considered here is IEEE 33 bus system. This proposed approach was implemented in MATLAB software.

KEYWORDS: Reconfiguration, DSTATCOM, PV Cell, Load Balancing (LB), DE.**INTRODUCTION**

The electrical energy generated at a generating station is carried to the consumers through a network of transmission and distribution systems. It is often grim to draw a line between the transmission and distribution systems of large power system. The main function of an electrical power distribution system is to supplies power to individual consumer premises. Distribution of electric power to different consumers is provided with much low voltage level. Distribution of electric power to all the consumers is done by distribution networks. In the past few decades the distribution systems were facing so many problems. There are two major sources of losses in power distribution systems. These are the transformers and power lines. In distribution system the power lines which connect the substation to the loads, one of the major sources of losses occurs in power lines. Virtually all real power that is lost in the distribution system is due to copper losses [1]-[3].

Distribution systems have two types of switches they are tie and sectionalizing switches. By changing the switches status between feeders, the structure of the distribution network will change and it is known as reconfiguration. The main objective of reconfiguration is to reduce losses, increase stability and reliability, improve voltage profile (VP), and relieve overload in the distribution network. [4]-[8].

Distribution flexible ac transmission system (DFACT) [11][12] devices are used in distribution systems with different applications and controlling methods for improving the power quality indices. DSTATCOM, unified power flow controller (UPFC), and dynamic voltage restorer (DVR) are widely used DFACT devices. To find the optimal location and capacity of DFACT devices has a considerable impact in distribution systems. The Distribution Static Compensator (DSTATCOM) [9][10] is a voltage source inverter based static compensator (similar in many respects to the DVR) that is used for the correction of bus voltage sags and it can provide the correct amount of leading or lagging reactive current compensation to reduce the amount of voltage fluctuations.

PV produces power when exposed to sunlight, a number of other components are required to properly conduct, control, convert, distribute, and store the energy produced by the array. In restructured power systems, the use of distributed generation energy resources including photovoltaic (PV), fuel cells, small wind turbines, etc. The advantage of distributed generation energy resources includes reduction in power loss, improvement in VP, and increase in the reliability of the network. To achieve the benefits of DG units, the selection of optimal locations and capacity is becoming the major problem [13][14].

H. B. Tolabi, M. Gandomkar, and M. Bahreyni Borujeni [15] discussed about the Reconfiguration and load balancing by software simulation in a real distribution network. Thereby minimum loss optimum performance has been obtained by the distribution network in this method. The drawback of this method is that it has low convergence.

A. Merlin and H. Back [16] proposed Minimal-loss operating spanning tree configuration in an urban power distribution system. It is one of the first papers based on reconfiguration in distribution system. But it is difficult to solve the problem due to complicate reconfiguration.

A. Kavousi-Fard and T. Niknam [17] described Multi-objective stochastic distribution feeder reconfiguration from the reliability point of view. To enhance the reliability of the system this paper assesses the DFR (Distribution Feeder Reconfiguration) strategy. It is a costless method and studied on an IEEE standard test system.

R. Kollu, S. R. Rayapudi, [18], explained A novel method for optimal placement of distributed generation in distribution systems using HSDO for power loss reduction and improve voltage profile. It depends on optimal placing and sizing of DG. This method is tested on IEEE 33 and 69 bus distribution system.

T. Xiangqian, X. Keqing, S. Ming [19], one of the main problem in the distribution system is the load unbalance. By placing the DSTATCOM, load unbalance as well as the reactive power can be compensated.

In this paper, the Differential Evaluation (DE) algorithm [20]-[23] has been used for simultaneous multi objective reconfiguration and optimal allocation of PV and DSTATCOM in Radial distribution network. The main objective of the work includes loss reduction, VP improvement, and equalizing the feeder load balancing (LB). In our proposed system a multi objective function is formulated to reduce real power loss, improve voltage profile and to perform load balancing of the distribution system the reconfiguration with photovoltaic array and DSTATCOM devices are used.

PROBLEM FORMULATION

Objective function

The objective function of this paper is to reduce real power loss, improve voltage profile and to perform load balancing of the distribution system [1].

Real power loss

The first term of objective function is real power loss that is defined by the equation (1)

$$P_{Loss} = \sum_{j=1}^{n_f} \sum_{k=1}^{n_s} R_k |I_k|^2$$

Where,

I_k – Is the current passing through line k

n_f – Is the total number of feeders

n_s – Total number of sections in the system

R_k – Resistance of the line section between buses k and $k + 1$

Voltage Profile improvement

The second objective of this work is to improve the voltage profile (VP) which is shown by VP index in equation (2).

$$VP = \frac{\sum_{j=1}^{n_f} \sum_{k \in lb} |V_k - V_{ref,k}|}{\dots} \quad (2)$$

Where,

- lb – Collection of the load buses
- $V_{ref,k}$ – Nominal voltage at load bus k .
- V_k – Voltage amplitude at bus k .

Feeder load balancing (LB)

The third term of the objective function is considered for the increase in the LB index of the lines in the feeders, which is shown in equation (3)

$$LB = \sum_{j=1}^{n_f} \sum_{k=1}^{n_s} \left(\frac{I_k}{\frac{1}{n_f} \sum_{k=1}^{n_f} I_k} \right)^2 \text{-----} (3)$$

Where,

- I_k – Current passing through line k
- n_f – Total number of feeders
- n_s – Total number of sections in the system

The different objective function is to be satisfied simultaneously; a comparison is required to get the best result.

DIFFERENTIAL EVOLUTION ALGORITHM

Price and Storn developed Differential Evolution algorithm to be a reliable and versatile function optimizer that is easy to use and give result in very short time period. It is a simple and extremely powerful evolutionary computation technique that solves real-valued problems based on the principles of natural evolution. The optimization process is conducted by means of three main operations: mutation, crossover and selection. Once every generation, each parameter vector of the current population becomes a target vector or parent vector. For each target vector, the mutation operation produces a new parameter vector called mutant vector, by adding the weighted difference between two randomly chosen vectors to a third (also randomly chosen) vector. The crossover operation generates a new vector, the trial vector, by mixing the parameters of the mutant vector with those of the target vector. If the trial vector obtains a better fitness value than the target vector, then the trial vector replaces the target vector in the following generation. Thus a new modified population is created after each generation and this continues until the iteration terminates or a global optimum solution is obtained.

The control parameters in the traditional DE the three parameters are N_p , C_r and F are these are dependent. Trial and error method adopted for tuning the parameters in DE require multiple optimization runs and is very laborious. More over the N_p , C_r and F parameter values obtained cannot ensure the optimization ergodicity completely in the search phase. Thus require the adaptation of the parameter values according to the problem, to find the optimum solution searching the entire domain of parameter values. Here two ways of adaptation of parameter values for DE are described.

Population formation of Differential Evolution Algorithm

The general scheme of the Differential Evolution method is quite similar to other evolutionary algorithms. At every generation G , Differential Evolution maintains a population P_g and N_p vectors of candidate solutions or parent vector to the problem, which evolve throughout the optimization process to find global solutions $P^g = [X_1^g, \dots, \dots, \dots, X_{N_p}^g]$

The population size i do not change during the optimization process. The dimension of each vector of candidate solutions correspond to the number of the decision parameters, D , to be optimized. Therefore,

$$X_i^G = [X_{1,j}^G, \dots, \dots, \dots, X_{D,j}^G] \quad i=1, \dots, N_p$$

General optimization process of differential evolution algorithm. The Differential Evolution optimization process is conducted by means of the following Operations:

1. Initialization

In order to establish a starting point for the optimization process, an initial population must be created. Typically, each decision parameter in every vector of the initial population is assigned a randomly chosen value from within its corresponding feasible bounds:

$$X_{j,i}^0 = X_j^{min} + \epsilon_j (X_j^{max} - X_j^{min}) \quad i=1, \dots, N_p, \quad j=1, \dots, D$$

ϵ_j = a uniformly distributed random number between a range [0, 1] generated anew for each decision parameter.

$X_j^{max} - X_j^{min}$ = the upper and lower bound for the Y decision parameter.

In general, uniform distributions are preferred, since they best reflect the lack of knowledge about the optimum's location. Preset parameter bounds define the domain from which the G vectors in this initial population are chosen. All vectors get a unique index for bookkeeping because each of them enters a competition. Two variables x1 and x2, which are chosen randomly within their upper (x2max, x1max) bound and lower (x2min, x1min) bound and the variables are within this contour. After the initial population is created, it evolves through the operation of mutation, crossover and selection.

2. Mutation

Mutation generally refers to an operation that adds a zero-mean random variable to one or more vector parameters. The distribution of difference vectors will depend on the distribution of vectors and this will be different for each objective function. At every generation G, each vector in the population has to serve once a target vector. For each target vector a mutant vector

$$X_i'^G = [X_{1,i}'^G, \dots, \dots, \dots, X_{D,i}'^G] \text{ is generated according to } X_i'^G = X_a^G + F(X_b^G - X_c^G)$$

Where,

X_a^G, X_b^G, X_c^G are randomly chosen vectors from the set $\{1, \dots, N_p\}$ and are mutually different and different to the target vector.

The indexes a, b, c are generated anew for each individual of the population.

F is a user defined constant (also known mutation scaling factor) target vectors are chosen randomly and these along with the mutation factor (F) are utilized to create the mutant vector μ_0 . Thus this operation controls the amplification of the differential variation.

Crossover:

In order to increase the diversity of the perturbed parameter vectors, the crossover operation is introduced. To the end, the trial vector

$$X_i''^G = [X_{1,i}''^G, \dots, \dots, \dots, X_{D,i}''^G]$$

This is created by mixing the parameter of the parent vector X_i^g and the mutant vector $X_i'^G$ by means of a series of D-1 binomial experiments in the form

$$X_{j,i}''^G = \begin{cases} X_{j,i}'^G & \text{if } \mu_j \leq C_R \text{ or } j = q \\ X_{j,i}^g & \text{Else} \end{cases} \quad i=1 \dots N_p$$

μ_j = an uniformly distributed random number within the range $[0,1)$, generated a new for each value j .

C_R = Crossover rate constant and is a user-defined parameter within the range $[0,1]$.

q = randomly chosen from the set $\{1 \dots D\}$ which is used to ensure that $X_i''^G$ get a least one parameter from $X_i'^G$

3. Uniform (binomial) crossover

It is defined as a process in which the independent random trials determine the source for each trial parameter. Crossover is uniform in the sense that each parameter, regardless of its location in the trial vector, has the same probability, of inheriting its value from a given vector. DE version of uniform crossover begins by taking a randomly chosen parameter from the mutant so that the trial vector will not simply replicate the target vector. Comparing CR to random value between (0, 1) determines the source for each remaining trial parameter. If random value between (0, 1) \leq CR, then the parameter comes from the mutant; otherwise, the target is the source.

5. Selection

To decide whether or not it should become a member of the next generation, the trial vector is compared to the target vector using a greedy criterion. The best individual is allowed to advance to the next generation. That is

$$X_i^{G+1} = \begin{cases} X_i''^G & \text{if } f(X_i''^G) \leq f(X_i^G) \\ X_i^G & \text{else} \end{cases} \quad i = 1 \dots N_p$$

The above said procedure is followed when the objective function is said to be minimized. For maximization of objective function the individual for next generation is selected as

$$X_i^{G+1} = \begin{cases} X_i''^G & \text{if } f(X_i''^G) \geq f(X_i^G) \\ X_i^G & \text{else} \end{cases} \quad i = 1 \dots N_p$$

All the solution in the population has the same chance of being selected as parent independent of the fitness value. If the parent is better it is retained in the population. By using this selection procedure, all individuals of the next generation are as good as or better than the individuals of the current population.

6. Termination

The iterative process can be terminated when any of the following criteria is met

1. An acceptable solution has been achieved with no more improvement in the solution. This is possible if the global optimum has been specified in the program.
2. The predetermined number of generations allowed has been achieved

ALGORITHM OF DE

STEP: 1 *Initialization of population*

$$P^0 = [X_1^0, \dots, \dots, \dots, X_{N_p}^0] \tag{4}$$

$$X_{j,i}^0 = X_j^{min} + \epsilon_j (X_j^{max} - X_j^{min}) \quad i=1, \dots, N_p, \quad j=1, \dots, D \tag{5}$$

Repetition of iteration until stop criteria is satisfied.

STEP: 2 *Mutation*

$$X_i^b = X_a^G + F(X_b^G - X_c^G) \tag{6}$$

Where

$a, b, c, i \in \{1, \dots, N_p\}$, and $a \neq b \neq c \neq i$

STEP: 3 *Cross Over*

$$X_{j,i}^{''G} = \begin{cases} X_{j,i}^G & \text{if } \mu_j \leq C_R \text{ or } j = q \\ X_{j,i}^G & \text{else } j=1 \dots D \end{cases} \quad i=1 \dots N_p \tag{7}$$

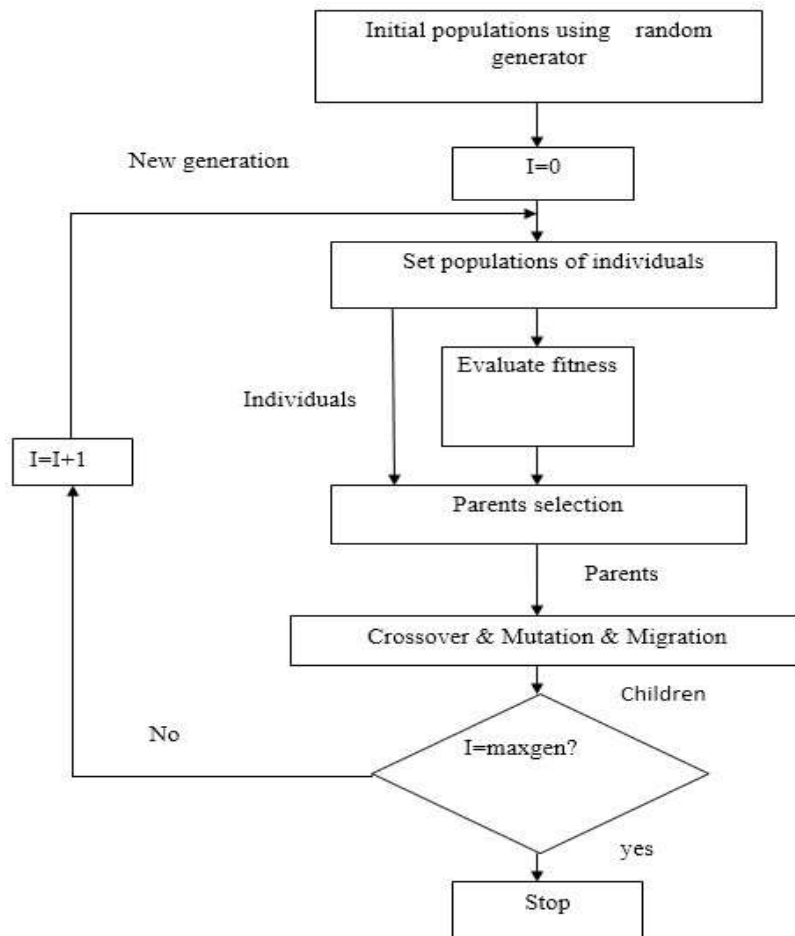
STEP: 4 *Selection*

$$X_i^{G+1} = \begin{cases} X_i^{''G} & \text{if } f(X_i^{''G}) \leq f(X_i^G) \\ X_i^G & \text{else} \end{cases} \quad i = 1, \dots, N_p \tag{8}$$

Increase of iteration count

End of repetition.

FLOW CHART FOR DE



SIMULATION AND RESULTS

Based on the proposed methodology, a program has been written in MATLAB software. In order to evaluate the performance of the proposed approach, the program has been applied on test systems at the nominal load. In this paper, five different cases have been considered to analyze the effectiveness of the proposed approach.

Case I: The base Case.

Case II: Reconfiguration. alone

Case III: Reconfiguration and PV allocation.

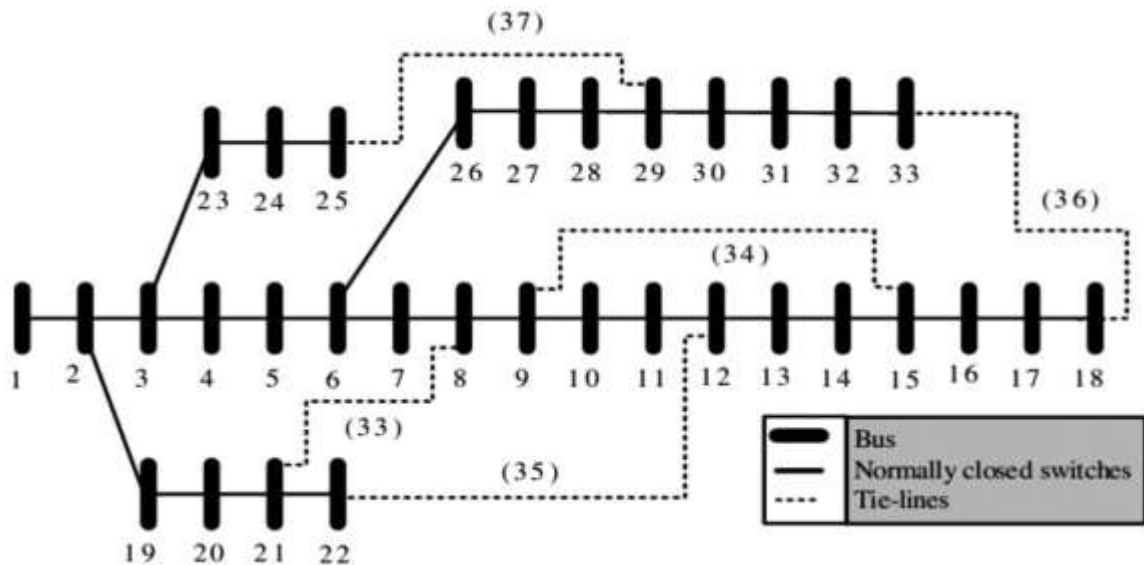
Case IV: Reconfiguration and DSTATCOM allocation.

Case V: Simultaneous Reconfiguration, PV, and DSTATCOM allocation.

TEST SYSTEM

The test systems that are used in this study have some tie lines. It is considered the total number of tie switches are maintained after reconfiguration. In other words, whenever one of the tie switches is closed, one of the closed switches will be opened and the network remains in radial structure simultaneously feeding all loads.

The test system is, 33-bus distribution system with a total load of 3.7 MW and 2.3 MVar having 5 tie and 32 sectionalizing switches. The power flow is performed using $S_{base} = 100\text{MVA}$ and $V_{base} = 12.66\text{ kV}$.



RESULT DISCUSSION

A. Case I: Base Case.

In this case the power flow is analysed using Backward/Forward sweep algorithm in the base case ie. Without reconfiguration and without placing PV and DSTATCOM. The observed results are presented in Table 1. It is observed from the result that, base case power loss is 223.7478kW. VP index is calculated as 0.0931. Load balancing is obtained as 67.1304.

Table 1: Base Case

Bus no	Voltage in p.u.	Angle in degree	Individual P loss	Individual Q loss
2	0.9966	0.0002	13.9300	7.2067
3	0.0015	0.0015	30.3210	15.4434
4	0.0024	0.0024	17.0920	8.7048
5	0.0034	0.0034	15.8091	8.0518
6	0.9525	0.0013	32.0755	27.6891
7	0.9446	-0.0052	6.3357	20.9430
8	0.9246	-0.0110	23.2367	16.7697
9	0.9147	-0.0142	9.5405	6.8543
10	0.9054	-0.0172	8.5034	6.0505
11	0.9053	-0.0172	0.0050	0.0016

12	0.9051	-0.0171	0.0156	0.0052
13	0.9814	0.0009	0.8219	0.6467
14	0.9802	0.0003	0.1697	0.2234
15	0.9799	0.0002	0.0162	0.0144
16	0.9795	0.0000	0.0221	0.0161
17	0.9787	-0.0005	0.0382	0.0510
18	0.9518	0.0012	0.0556	0.0436
19	0.9942	-0.0007	2.8540	2.7235
20	0.9742	-0.0073	22.9695	20.6973
21	0.9687	-0.0100	5.4209	6.3330
22	0.9595	-0.0153	8.0393	10.6295
23	0.9550	-0.0162	4.3198	2.9517
24	0.9468	0.0185	7.0786	5.5896
25	0.9424	-0.0198	2.0124	1.5747
26	0.9423	-0.0198	0.0069	0.0035
27	0.9421	-0.0198	0.0096	0.0049
28	0.9381	-0.0019	3.8829	3.4235
29	0.9370	-0.0021	0.1255	0.1093
30	0.9350	-0.0000	1.6478	0.8393
31	0.8972	-0.0216	5.9537	5.8840
32	0.9810	-0.0123	0.9989	1.1642
33	0.9807	-0.0124	0.0130	0.0203

B. Case II: Reconfiguration. alone

By changing the tie line switch status between feeders, the structure of the distribution network will change and it is known as reconfiguration. The main objective of reconfiguration is to reduce losses, increase stability and reliability, improve voltage profile (VP), and relieve overload in the distribution network. The base case system only with reconfiguration observed from the table, the power loss is 69.2462. The VP index calculation is 0.0348 and the load balancing is obtained as 75.2964.

Table 2. The base system only with reconfiguration

Min fit	Tie switches	Power loss	Voltage profile	Load balancing
144.5774	7, 12, 8, 15, 23	69.2462	0.0348	75.2964

C. Case III: The base system with reconfiguration and PV allocation.

The above table are represented as reconfiguration along with pv array. The power losses are can be obtained as 82.2269. The voltage profile calculation is obtained as 2.9543. The load balancing is obtained as 46.1778.

Table 3. Reconfiguration with photovoltaic array

Min fit	Tie switches	PV- loc	PV- size	Power loss	Voltage profile	Load balancing
131.3590	33, 34, 35, 32, 31	16	1.6480	82.2269	2.9543	46.1778

D. Case IV: The base system with reconfiguration and DSTATCOM allocation

In reconfiguration along with DSTATCOM can be represented in the above table. The power loss can be calculated as 77.4781 and the voltage profile indices are 0.0354 and the load balancing can be obtained as 70.6556.

Table 4 Reconfiguration with DSTATCOM

Min fit	Tie switches	Dstat- loc	Dstat- size	Power loss	Voltage profile	Load balancing
148.1690	7, 12, 8, 15, 22	17	649.5874	77.4781	0.0354	70.6556

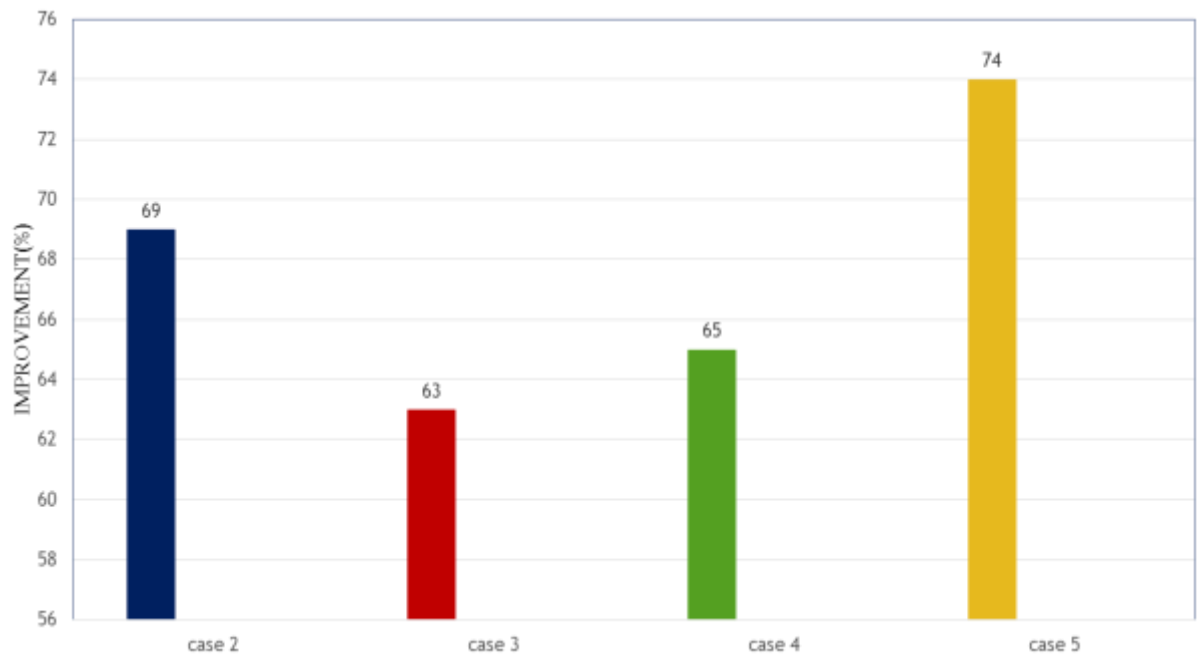
E. Case V: The base system with simultaneous reconfiguration, PV, and DSTATCOM allocation.

The above table represented as reconfiguration along with both photovoltaic array and the DSTATCOM devices. From this case the power loss, voltage profile and the load balancing are reduced as compared to other cases. The power loss can be reduced as 58.1162, voltage profile can be obtained as 0.0208 and the load balancing is obtained as 65.0859.

Table 5 Reconfiguration along with PV and DSTATCOM

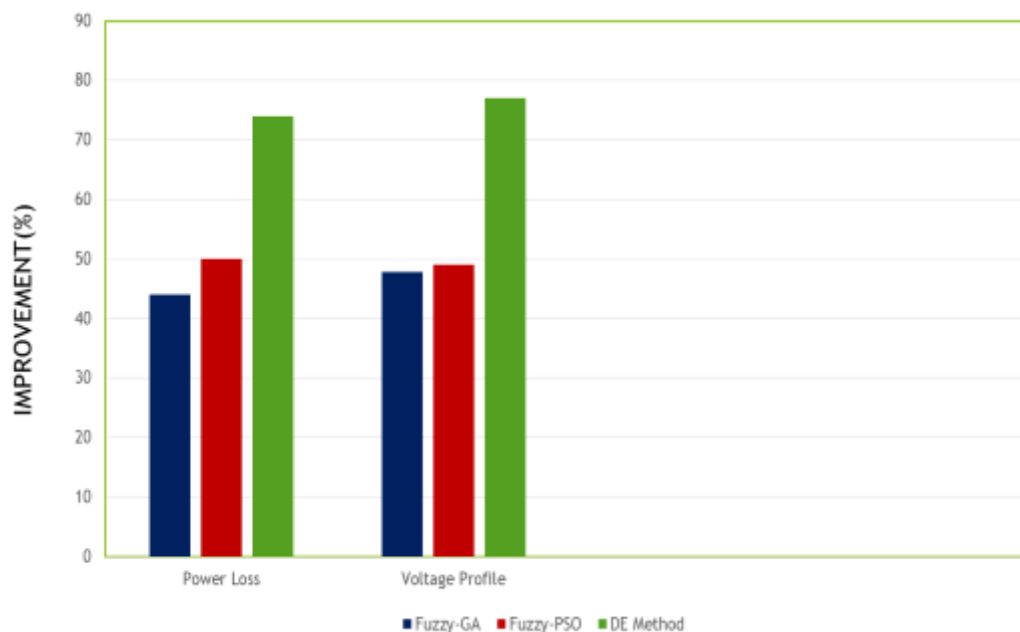
Min fit	Tie switches	Dstatcom-loc	Dstatcom-size	PV-loc	PV-size	Power loss	Voltage profile	Load balancing
123.2288	7,13,21,15,28	9	536.8143	24	1.7818	58.1162	0.0208	65.0859

Power loss comparison



By comparing the improvements obtained for cases II to V with the base case (case I), it is found that simultaneous reconfiguration with PV and DSTATCOM allocation (case V) has improvements in power loss as 74%. It is better than other four cases.

Comparison of power loss and voltage profile with other methods



The above chart represents the percentage improvements in P_{loss} , LB, and VP indices using the fuzzy-GA, fuzzy-PSO, and DE method approaches for case V as compared to the base case (case I) at nominal load. In this paper, a differential evaluation based algorithm has been presented for simultaneous reconfiguration and allocation of PV and DSTATCOM units.

CONCLUSION

The proposed approach is employed to mitigate the power loss, VP improvement, and equalizing the feeder LB in distribution system. To test the effectiveness of the proposed approach, five different cases have been tested on 33-bus test system and a real distribution network. Among the five cases, the multi objective reconfiguration and simultaneous PV and DSTATCOM allocation case is found to be better than the others. For 33-bus system, the loss reduction is 74% is improved and the VP indices are 77% improved compared with the base system. Obtained results are compared with the fuzzy-GA and fuzzy-PSO at nominal load and found to be better than the above-mentioned approaches because of the lowest fitness. The performance of the differential evaluation is better as compared to the other method. Furthermore, the reconfiguration along with PV and DSTATCOM is more advantageous than the individual one. Finally, obtained results confirm the satisfactory operation of the proposed approach at different load levels.

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