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Network Reconfiguration with Optimal allocation of Capacitors and DG units for Maximizing DISCOs Profit in a Restructured Power Market

***Abstract**. Technological developments in the deregulated electricity market enable competitive environment for Distribution Companies (DISCOs) and DGs to maintain reliable, effective and secure electrical power to the consumers. The performance of the DISCOs in radial distribution networks is primarily relied upon the power loss and voltage stability. Best practice to mitigate the losses in the distribution network includes capacitor placements, induction of DGs and network reconfigurations. These process help out to improve the system voltage profile and minimize the power losses and thereby maximising the profit of the distribution companies. In this paper, recently developed and comprehensive moth flame optimization algorithm is presented for maximizing the profit of the DISCOs under competitive environment. The execution process of network reconfiguration and proper placement and sizing of capacitors and DG units are taken care of by MFO algorithm. Reconfiguration of network is a mechanism of shuffling existing pattern of feeders duly changing ON and OFF status of tie-line switches to improve the performance of the DISCOs. The algorithm also minimizes the various types of cost such as investment, maintenance and operational cost. The proposed MFO algorithm is implemented on IEEE 33 node and 69 node systems to evaluate its performance. Evaluation of solution in MATLAB software demonstrates the skills of MFO in DISCOs.*

***Streszczenie.** Rozwój technologiczny na zderegulowanym rynku energii elektrycznej umożliwia konkurencyjne środowisko dla spółek dystrybucyjnych (DISCO) i dyrekcji generalnych w celu utrzymania niezawodnej, efektywnej i bezpiecznej energii elektrycznej dla konsumentów. Wydajność DISCO w promieniowych sieciach rozdzielczych zależy przede wszystkim od strat mocy i stabilności napięcia. Najlepsza praktyka łagodzenia strat w sieci dystrybucyjnej obejmuje rozmieszczenie kondensatorów, indukcję DG i rekonfiguracje sieci. Procesy te pomagają poprawić profil napięciowy systemu i zminimalizować straty mocy, a tym samym maksymalizować zysk spółek dystrybucyjnych. W niniejszym artykule przedstawiono niedawno opracowany i kompleksowy algorytm optymalizacji płomienia ćmy w celu maksymalizacji zysku DISCO w konkurencyjnym środowisku. Procesem wykonania rekonfiguracji sieci oraz właściwego rozmieszczenia i doboru kondensatorów i jednostek DG zajmuje się algorytm MFO. Rekonfiguracja sieci to mechanizm tasowania istniejącego wzorca linii zasilających, odpowiednio zmieniający stan ON i OFF przełączników linii łączącej w celu poprawy wydajności dysków DISCO. Algorytm minimalizuje również różnego rodzaju koszty, takie jak koszty inwestycyjne, konserwacyjne i operacyjne. Proponowany algorytm MFO jest zaimplementowany w systemach IEEE 33 węzłów i 69 węzłów w celu oceny jego wydajności. Ocena rozwiązania w oprogramowaniu MATLAB demonstruje umiejętności MFO w dyskotekach. (**Rekonfiguracja sieci z optymalną alokacją kondensatorów i jednostek DG w celu maksymalizacji zysku DISCO na zrestrukturyzowanym rynku energii**)*

Keywords: Restructured Power Market, Network Reconfiguration, Capacitor and DG placement, Voltage stability, cost-benefit analysis of DISCOs, MFO algorithm.
Słowa kluczowe: sieć zasilająca, usytuowanie kondensatora I generatora, stabilność napięciowa.

Introduction

The electrical network system can be broadly classified in to generation, transmission and distribution sectors. The power distribution segment consists of distribution companies which is liable for supply and distribution of power to the consumers. It is significant / important to note that this sector is the weakest position in terms of financial and operational aspects. Ever increasing load demand in order to meet the instinctive development of the prevailing systems, make the radial distribution system as an acute and complex segment for the distribution companies. The primary drawbacks of the distribution system is that its higher R/X ratio and lower voltage level which results in more system losses, poor power factor and inadequate stability [1, 2]. Hence, the distribution system needs an accurate planning for improving the reliability and quality of the service which in turn improves the profit of the company. Accordingly, the process of restructuring in the electricity market opens up different avenues to revenue of the companies. Therefore, a strategy must be precisely evolved to address these kinds of problems.

Generally, capacitor banks are widely used in the power system to minimize line losses, support reactive power, and enhance voltage profile and to improve power factor. These capacitors may serve the purpose only when it is exactly placed in the system. It is well known that the distribution system is most vulnerable to line losses. A portion of these losses can be compensated by connecting capacitor bank in the network [3]. Similarly, installation of DGs in the distribution network provides a better choice to power engineers for taking a decision on scheduling pattern. DGs have the ability to enhance the system performance without making pollution to the environment.

Apart from above methods, several researches have been carried out to mitigate the losses and to enhance the system performance. Network reconfiguration is another viable option for this problem [4], since it does not need any additional components involving financial constraints. By implementing, the above methods in the distribution system, it is possible to improve the system performance and thereby making Discos as profit making entity.

Researchers have proposed numerous formulations to showcase the applicability of DGs in network system. DGs are optimally used in the deregulated electricity market [5].The placement and profit for DGs are selected on the concept of locational margin price (LMP). LMP serves to estimate the short run marginal cost of the consumed power. Consumers bill payment, calculated as a multiplication of LMP and load individual load bus.

The impact of bilateral contract business among distribution companies and upstream network and between consumers is explained based on hybrid market rules in [6]. Genetic Algorithm based tabu search method is attempted to analyze an ideal location of DG units with multiple types for the purpose of optimization of economical, technical and market constraints.

Ameli *et. al* [7] suggests an economic model for establishing DG units by considering both DG owners and distribution company profit simultaneously. Multi-objective PSO approach was applied in its case studies using IEEE 33 bus distribution system evolving best result for the allotment, contract price and size for power generation. The said approach not only deals with operational procedures but also analyses the economic concerns of DISCOs and DGOs.

Novel multi-objective method for the establishment of DG at optimum place, size and contract market price are discussed in [8], wherein it was assumed that DG owners planned to erect three dispatchable unit and synchronous DG units in a system. The approach is based on operational and economic perspective from the both DG owners and the DISCOs. Multi objective PSO has been suggested to review the problem subject to standard operational constraints.

A case study based on cost benefit of DG allocation in distribution system has been described in [9]. This method is used to maximize the profit margin by an optimization method to identify optimal placement of capacitors and DG units. This method deals with different economic and technical issues like energy losses, capacity of capacitors and DG units to attain the objectives. The cost of grid power has also taken into account to get back the initial expenditure within a specified period. The PSO technique has been adopted to work out the problem of maximizing the profit. The method was tested using IEEE 39 and 69 systems.

In most of the situations, power networks are extended in a radial pattern. Thus, the induction of DGs into the distribution system may disturb the power flow in the distribution feeder networks. To have a reliable and secure system, DG units essentially needs accurate control and appropriate operational strategy.

A multi-objective benefit model for distribution system by considering energy storage system and demand response program is elaborated in [10]. In this work, two objective functions are discussed; particularly DISCOs and DGO benefit maximization. This method utilizes ε-constraint technique and fuzzy model to solve multi-objective problem.

Since, power demand is growing progressively, it is obligatory to expand the capacity of distribution network. For this the distribution network management, must offer wide opportunity for the private participant to get profit from their investments / assets /contributions. So the best option for the private participants is to establish DGs [11]. Discos have to / must made power purchase agreement (PPA) with DGO. Here, exact location, sizing and PPA charges are important components which are thoroughly discussed in this same reference. The suggested model has been solved by NSGA II. Since it realize / obtains /achieves non dominated solution, Discos and DGOs can present their permanent choices into practice. Simulation studies are carried out using IEEE 33 bus system.

In ref [12] a novel method has been suggested to decide simultaneously the optimal location and successful operation of DGs. Two phase analysis is done as follows; In Phase I outlines the optimal placement of DGs by multi objective optimization problem, wherein energy loss reduction, improvement of voltage regulation and voltage profile were the prime objectives. To solve the multi objective problem a pareto frontier differential evolution algorithm has been modelled. In Phase II, bi-level optimization with two agents is applied focus to maximized income of the DG owners added with total optimal payment of the DISCO. Moreover, to choose the optimal contract prices, game theory is used. Game theory helps in finding an optimal solution in line with economic issues like maximized revenue of DG owners and the optimal payment of DISCOs.

Role of distribution networks is remarkable in providing electrical power to the end consumers. However, the energy loss in the distribution system is high and hence the voltage regulation is low. There are many choices to curtail line losses and to build up the voltage profile such as reactive power support, rising the operating voltages and adjustment of loads. These approaches are feasible to implement technically but require much investment. Distribution network reconfiguration is seems to be the effective option to solve these problem, which may not require much financial requirements. Reconfiguration is usually done by either opening or closing the contacts in order to frame the new network topology for minimizing the power losses while satisfying operational constraints.

A model has been reported in reference [13] for occasional reconfiguration of existing distribution network which is integrated with different locations of transmission network, by considering the competitive environment. The focus of the work is to reduce the expense of purchased power with hourly locational marginal prices (LMP) of wholesale market, received from multiple nodes of distribution and transmission systems. Bilateral contract were also made with DGs. The daily load pattern of residential, commercial, official and educational centres were also taken into account. The presented model has been investigated by Genetic Algorithm and a straight forward sub algorithm, which is suitable for online applications. The developed strategy is evaluated with IEEE16 and 204 bus test systems.

The perception of DG owners and distribution companies are considered in ref [14]. A multi-objective technique was adopted for deciding optimum DG allocation, sizing and contract prices. Apart from diverse benefits of DGs, weak strategy in power dispatching and management of DGs are the major threat for distribution system operation. PSO algorithm has been used to attain the objectives. This method not only determines operational aspect, but also enhances the reliability measures.

A method of calculation of distribution marginal price (DMP) is explained in ref [15]. The objective of this article is to assess the DMP for both consumers and power producers individually. For this assignment, the first phase of the procedure lay down the cost by which producer have to sell the power. To achieve this objective, contribution of every node becomes important by the way of line losses of the network. When the losses of the system decreases, producers will make a noticeable profit. During next phase of the process, DMP is calculated for the end consumers. Then, system operator allocates the profit among the consumers and hence there is a reduction in their payments.

Optimal distribution network reconfiguration and DGs placement are the feasible choice for the betterment of technical and economic conditions of distribution system. A DSR model is defined to improve the DG owners profit and to reduce the discos cost has been pointed out in ref [16]. Scenario based method has been adopted to handle the irregularities in wind power production, electricity cost and demand. The defined model is tested through ε-constraint approach and the final result is obtained by fuzzy criterion. It is a MINLP problem and it is applied on IEEE33 bus distribution system. Different case studies have been performed to show the applicability of this approach. Moreover, an analysis is done to express contract price of wind power on the intention of DISCOs and DG owners. The results reveal participation among DSR and DG allocation practices. Finally, it was proved that the line losses of the system are moderately reduced, when an agreement is arrived between DG owners profit and DISCOs cost.

Problem formulation

The cost evaluation and benefit evaluation of allocation of Capacitors and DG units in a network is represented as below:

Cost evaluation of DG units and Capacitors allocation

a. Investment cost

The costs of capacitor banks and DG units, inspection charges, location for DGs and capacitor placements, erection and planning of equipment's etc. are treated as investment costs. Then the costs is given by the equation (1),

$$C_1 = \sum_{i=1}^{NDG} K_{DGi} \times IC_i + \sum_{i=1}^{NCap} K_{capj} \times IC_j \tag{1}$$

b. Operating Costs

Operational costs of Capacitor and DG units depend upon utilization of these units to meet the consumers electrical power demand. Since the operational cost of capacitor is zero, it involves only by DGs. Then the operating cost is given by the equation (2)

$$C_2 = \sum_{i=1}^{NDG} \left[K_{DGi} \times OC_i \right] \times \Delta T \tag{2}$$

If IF is inflation rate and IR refers interest rate, then the present worth factor is given by the equation (3)

$$\text{Present worth Factor, } \beta^t = \sum_{t=1}^{n} \left(\frac{1+IF}{1+IR} \right)^t \tag{3}$$

For an operating cost in a planning year, present worth value is given by the equation (4)

$$PWV(C_2) = \sum_{i=1}^{NDG} \left[K_{DGi} \times OC_i \right] \times \Delta T \times \beta^t \tag{4}$$

c. Maintenance Costs

Yearly maintenance cost includes electrical and mechanical overhaul cost for DG units and Capacitors which does not include placement of capacitors and DG units and given by the equation (5)

$$C_3 = \left[\sum_{i=1}^{NDG} \left(K_{DGi} \times IC_i \right) \times MC_{DGi} + \sum_{i=1}^{NCap} \left(K_{capj} \times IC_j \right) \times MC_{capj} \right] \tag{5}$$

The annual cost present worth value during the period of planning is estimated as in equation (6)

$$PWV(C_3) = \left[\sum_{i=1}^{NDG} \left(K_{DGi} \times IC_i \right) \times MC_{DGi} + \sum_{i=1}^{NCap} \left(K_{capj} \times IC_j \right) \times MC_{capj} \right] \times \beta^t \tag{6}$$

Benefit evaluation of DG units and Capacitors allocation

a. Distribution line active power demand reduction

Energy delivered to Grid in a segment over ΔT time is given in equation (7),

$$B_1 = \sum_{i=1}^{NDG} K_{DGi} \times EP_G \times \Delta T \tag{7}$$

The present worth value of power generated by distribution company is given by the equation (8)

$$PWV(B_1) = \sum_{i=1}^{NDG} K_{DGi} \times EP_G \times \Delta T \times \beta^t \tag{8}$$

b. Revenue from loss reduction

The loss minimization is the primary objective of any distribution company is to maximize the profit. Equation (9) represents the revenue from the process of loss minimization by the installation of DGs and capacitors,

$$B_2 = \sum_{i=1}^{NDG} \sum_{j=1}^{NCap} \Delta LOSS_{ij} \times EP_G \times \Delta T \tag{9}$$

The present worth value for loss minimization revenue in a period of planning is given by equation (10),

$$PWV(B_2) = \sum_{i=1}^{NDG} \sum_{j=1}^{NCap} \Delta LOSS_{ij} \times EP_G \times \Delta T \times \beta^t \tag{10}$$

Objective function for DISCOs profit

Maximum profit of DISCOs is given by the equation (11) and (12),

$$Max\ Z = Benefits - Investments \tag{11}$$

$$MaxZ = \sum_{i=1}^{NDG} \left[K_{DGi} \cdot EP_G + \sum_{j=1}^{NCap} \Delta LOSS_{ij} \cdot EP_G - K_{DGi} \cdot OC_i \right] \Delta T . \beta^t - \sum_{i=1}^{NDG} \left[K_{DGi} \cdot IC_i \left\{ 1 + MC_{DGi} . \beta^t \right\} \right] - \sum_{j=1}^{NCap} \left[K_{Cap} \cdot IC_j \left\{ 1 + MC_{capj} . \beta^t \right\} \right] \tag{12}$$

System Constraints

a. Constraints for Power balance

Constraints for active and reactive power are given in equation (13) and (14),

$$P_i = \sum_{j=1}^{N} V_i V_j \left[G_{ij} \cos\left(\delta_i - \delta_j\right) + B_{ij} \sin\left(\delta_i - \delta_j\right) \right], \forall i = 1,2,3,......N \tag{13}$$

$$Q_i = \sum_{j=1}^{N} V_i V_j \left[G_{ij} \sin\left(\delta_i - \delta_j\right) - B_{ij} \cos\left(\delta_i - \delta_j\right) \right], \forall i = 1,2,3,......N \tag{14}$$

b. Voltage constraints

Each bus must satisfy the following voltage constraint as in equation (15),

$$\left| V_i \right|_{\min} \le \left| V_i \right| \le \left| V_i \right|_{\max}, \forall i \in N \tag{15}$$

c. Current limit

Current flowing in the distribution segment should not exceed from their maximum ratings as given in equation (16),

$$I_i \le I_{iRated}, \forall i \in N_{Br} \tag{16}$$

d. Constraints for size of capacitors and DGs

The capacity of installed capacitors and DGs in the proposed system is limited to either equal or less than thirty percent of the substation rated capacity in order to preserve the concept of DG over centralized power generation as given in equation (17) and (18).

$$S_{DG} \le 0.30 S_{T_{Real}} \tag{17}$$

$$S_{Cap.} \le 0.30 S_{T_{React.}} \tag{18}$$

Solution methodology

Overview of Moth – Flame Optimization (MFO) Technique

In general, most of the optimization algorithms have been constrained to local optima which prevent the algorithm from reaching their perfect optimal solution besides it suffers from huge computational burden and time consumption. Moth fly optimization algorithm (MFO) [17, 18] which was recently introduced. It was well received by the researchers and has been subjected to solve multi objective optimization problems. It gives exemplary performance over other sort of algorithms because of its excellent pattern of convergence. This technique has been framed on the idea of biological behaviour of moth fighting flames in the field. It inherits the population of moths in order to do the optimization process and each and every moth have to upgrade their position in line with the flame. It prevents the moth to escape from the entrapment of local optima and to recover its inspection process in the search space. Especially, its realization is on the virtue of transverse orientation process. The navigational behaviour of the moth has encouraged the researchers for implementing this kind of optimization problem. The mathematical formulations and characteristics of MFO are considered from the references [14, 15].

Execution of MFO Algorithm

The following procedural steps are followed for optimal allocation and sizing of combined DG and capacitor with network configuration to evaluate the profit of DISCOs in a competitive electricity market using MFO algorithm. The proposed approach also does the various processes such as cost of installation, running cost and maintenance cost of the Capacitors and DG, Revenue, node voltage enhancement, Power loss minimization, optimal placement and sizing of Capacitors and DG in radial distribution system.

1. Read the line data, bus data and load data of RDS, cost of installation, running cost and maintenance cost of the capacitor and DG, Interest rate, Inflation rate, Market price and Planning period.
2. Run the distribution power flow and calculate the loss using exact loss formula for base case.
3. Choose the number of Capacitors and DG to be used to in Radial Distribution System.
4. Set the parameters of MFO algorithm such as Population, dimension, maximum number of iterations, lower and upper bound (size and node Capacitor and DG respectively).
5. Fix iteration=1
6. Compute fitness (i.e. loss in network) for each and every moth by installing DG and Capacitor at their respective buses using eqn. (15).
7. Evaluate the objective functions of each moth and determine the profit of DISCOs.
8. Update the position of flame and save the best fitness values in an array corresponding to eqn. (16)
9. Update the record of flames and the flames are arranged using eqn. (17) based on their fitness values
10. Estimate the present position of moths.
11. If all constraints are satisfied move to next step, if all constraints not satisfied go to step 6.
12. Go to step 13, if maximum number of iterations is attained. else go to step 5.
13. Display the global best solution of various cost and DISCOs profit and STOP the program.

Results and discussion

With a view of assessing the superiority of the proposed MFO, a test has been carried out on 33 bus and 69 node redial distribution network under deregulated environment. The global solution of deregulated system is more complex and competitive than conventional RDS. The proposed methodology has more ability to achieve the best numerical solutions.

The optimization process has been performed in MATLAB version R2014a Intel core i3 PC with 2.10 GHz speed and 4GB RAM. Generally first bus is considered as reference bus and as connected with substation for both 33 and 69 bus test system. The MFO is viewed as a parameter less algorithm which has only control parameters. Here, population size of fifty and maximum number of iterations is 500. The distribution load flow analysis has been carried out for the purpose network solution in each of the cases. The simulation results of two different test systems are described as follows.

Test system 1: 33-node RDS

In this test case, capacitors and DG placement are carried out in the 33-node RDS with planning period of 10 years. Network reconfiguration is also made to improve the voltage profile and profit of DISCOs. The projected MFO is properly optimized the location and size of the DG and capacitor. The best placement and tuned value of DG and capacitor are 30, 18 and 1.5 MW, 0.9 MVAr respectively. The tie-line switches 33, 34, 35, 36 are used for network reconfiguration. The switches 7, 28, 12, 15, 21 are opened for enhancing the voltage stability by proposed MFO method. The one line diagram of network Reconfiguration with positioning of DG and Capacitor in 33-bus test system by proposed method is displayed in figure1. The voltage profile and VSI for base case and reconfiguration with placement of DG and capacitor are graphically given in figure 2 and figure 3 respectively.

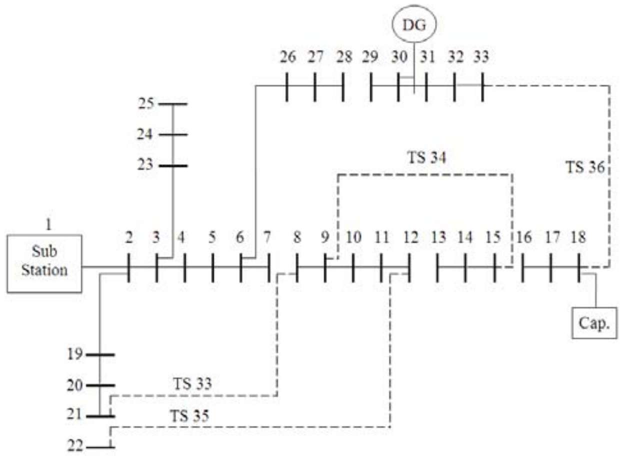

Fig. 1. Network Reconfiguration by installation of DGs and Capacitor in 33-node test system

Table 1. 33-node test system

Parameters	Optimal Value
Open switches	7, 28, 12, 15, 21
Tie-line switches	33, 34, 35, 36
DG Optimal placement	30
Capacitor Optimal placement	18
Capacitor Optimal sizing	0.9 MVAr
DG Optimal sizing	1.5 MW
Voltage stability index (p.u)	0.91256
Minimum Voltage (p.u)	0.97740

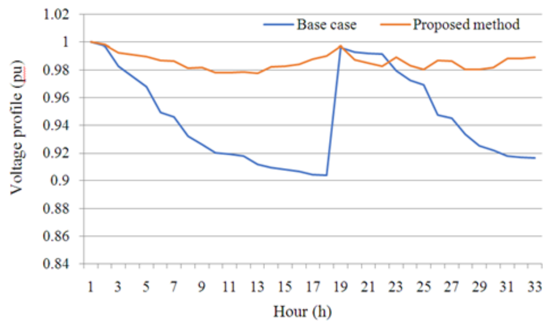

Fig. 2. Voltage profile for base case and Reconfiguration by the installation of DG units and capacitors for 33 node test system

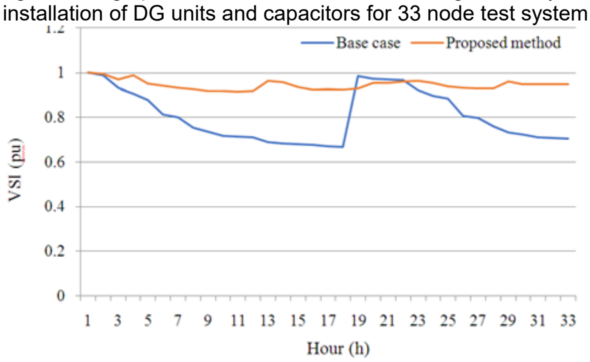

Fig. 3. VSI for base case and Reconfiguration with installation of DG and capacitor in 33node test system

The system variables are efficiently optimized and projected in Table 1. This table clearly explains the installation and sizing of DG and capacitors, minimum voltage and minimum VSI and power loss. The power loss of base case and existing PSO method is 221 KW and 45.723 KW respectively. Therefore, proposed method provides minimum power loss compared with base case and PSO method.

Table 2. Cost-Benefit analysis of DISCOs for 33 node test system

Costs, Benefits and Profits of DISCOs	**Values (Rs)**
Capacitor Installation cost	9×10^4
DG Installation cost	375×10^5
Reduction in purchased energy benefits	4.99×10^8
Loss reduction benefits	5.4979×10^7
DG Maintenance cost	6.342×10^7
DG Operational costs	2.495×10^8
Capacitor Maintenance cost	1.8988×10^5
Planning period	10 year
Total profit of DISCOs	**2032.8×10^5**

Table 3. Comparison of Various Cost and Benefits of DISCOs for 33-nodetest system

Parameters	**Value of Various costs, Benefits and Profit of DISCOs**	**Value of Various costs, Benefits and Profit of DISCOs**
	PSO [21]	**MFO (Proposed)**
Location DG and Capacitor	8 30	30 18
Size DG and Capacitor	1.5 (MW) 0.9 (MVAr)	1.5 MW 0.9 MVAr
Network Reconfiguration	No	Yes
Open switches	-	7,28,12,15,21
Tie-line switches	-	33, 34, 35,36
Planning period	10 year	10 year
Installation cost of DG (Rs)	375×10^5	375×10^5
Installation cost of Capacitor (Rs)	9×10^4	9×10^4
Benefits of loss reduction (Rs)	4.35×10^7	5.4979×10^7
Benefits of reduction in purchased energy (Rs)	4.99×10^8	4.99×10^8
Operational costs of DG (Rs)	2.49×10^8	2.495×10^8
Maintenance cost of DG (Rs)	6.34×10^7	6.342×10^7
Maintenance cost of Capacitor (Rs)	1.94×10^5	1.8988×10^5
Total profit of DISCOs (Rs)	**1937.94×10^5**	**2032.8×10^5**

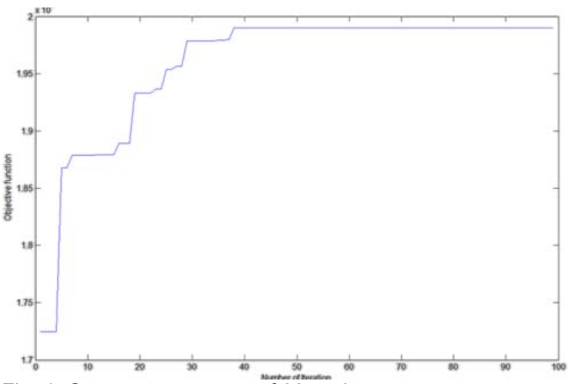

Fig. 4. Convergence curve of 33-node test system

In the DISCOs, various cost, benefits and profit are calculated by using the MFO method. The simulation results of the 33 bus system are described in Table 2. The Convergence curve of 33-bus test system is graphically displayed in figure 4. This table 3 explains the cost-benefit analysis of DOSCOs considering network reconfiguration with DG and capacitor placement. From the table, the proposed method having maximum profit, minimum power loss with less computational time compared with PSO method.

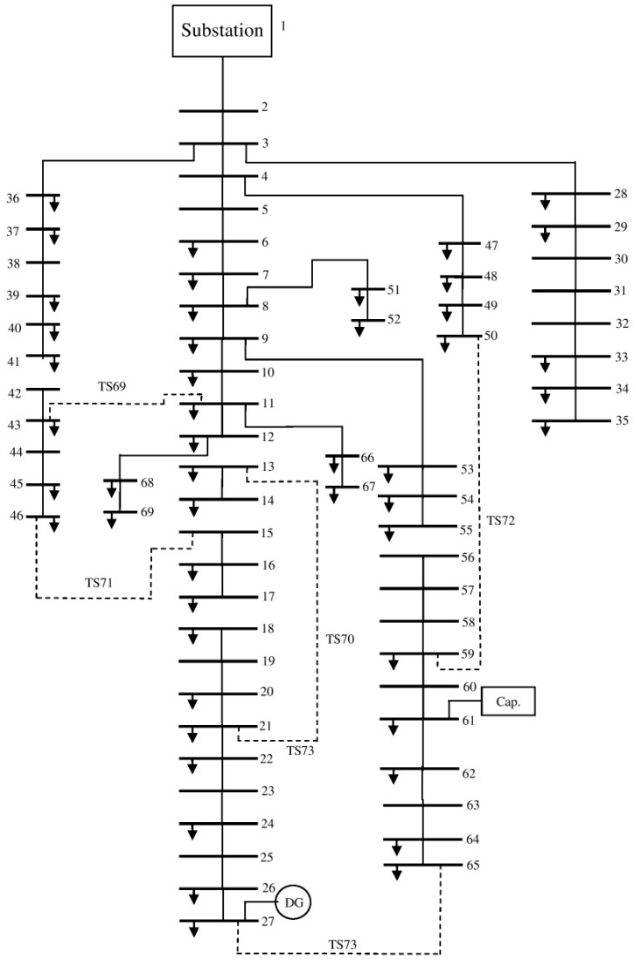

Fig. 5. Network Reconfiguration with placement of DG and Capacitor in 69 node test system

Test case 2: 69-node test system

In order to validate the applicability of the MFO algorithm, it is tested on a of 69 bus test system to obtain maximum profit of DISCOs. Planning period of Ten years is considered for this process. The MFO algorithm computes the required configuration with best location and size of the DG and capacitor. The one line diagram of network reconfiguration with placement of DG and Capacitor in 69 bus test system is shown in figure 5. The switches 14, 17, 55, 12, 41 are opened and connecting the tie-line switches 69, 70, 71, 72, 73 for improving the voltage profile and maximum profit of DISCOs. MFO algorithm efficiently identifies the location of DG and capacitor which is placed at bus 62 and 27 with optimal value of 1.5 MW and 0.8 MVAr respectively.

The Voltage profile and VSI for base case and reconfiguration with placement of DG and capacitor in 69-bus test system are graphically reported in figure 6 and figure 7 respectively. The optimized values of system variables including network loss, minimum voltage and minimum VSI are given in Table 4.

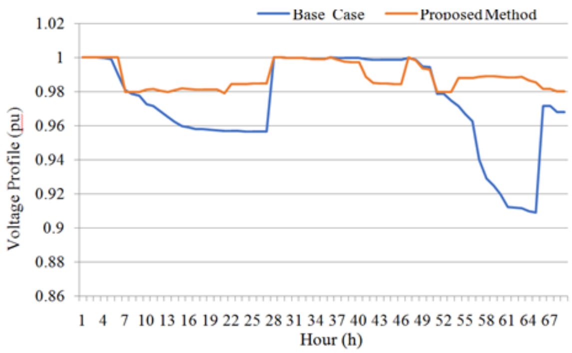

Fig. 6.Voltage profile for base case and Reconfiguration with placement of DG and capacitor in 69-bus test system

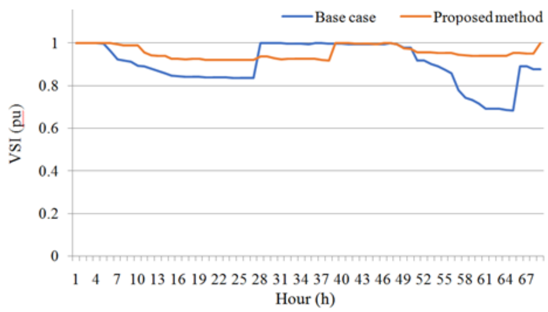

Fig. 7. VSI for base case and Reconfiguration with placement of DG and capacitor in 69-bus test system

Table 4. Optimal location and sizing of DG and capacitor for 69-node DISCOs considering network reconfiguration

Parameters	Optimal Value
Open switches	14, 17, 55, 12, 41
Tie-line switches	69, 70, 71, 72, 73
DG Optimal location	61
Capacitor Optimal location	27
DG Optimal sizing	1.5 MW
Capacitor Optimal sizing	0.8 MVAr
Minimum Voltage (p.u)	0.97985
Voltage stability index (p.u)	0.91896
Power loss (KW)	24.05

Table 5. Cost-Benefit analysis of DISCOs for 69-nodetest system

Costs, Benefits and Profits of DISCOs	Values (Rs)
DG Installation cost	375×10^5
Capacitor Installation cost	10.5×10^4
Loss reduction benefits	6.684×10^7
Reduction in purchased energy benefits	4.99×10^8
Operational charges of DG	2.495×10^8
Maintenance charges of DG	6.342×10^7
Maintenance charges of Capacitor	1.8988×10^5
Planning period	10 year
Total profit of DISCOs	**2151.4×10^5**

Table 6. Comparison of Various Cost and Benefits of DISCOs for 69-nodetest system

Parameters	Value of Various costs, Benefits and Profit of DISCOs	
	PSO [56]	MFO (Proposed)
	61	61
Capacitor Location	61	27
DG Size	1.5 MW	1.5 MW
Capacitor Size	1.2 MVAr	1.05 MVAr
Network Reconfiguration	No	Yes
Open switches	-	14, 17, 55, 12, 41
Tie-line switches	-	69, 70, 71, 72, 73
Planning period	10 year	10 year
Installation cost of DG (Rs)	375×10^5	375×10^5
Installation cost of Capacitor (Rs)	1.2×10^5	10.5×10^4
Benefits of loss reduction (Rs)	6.52×10^7	6.684×10^7
Benefits of reduction in purchased energy (Rs)	4.99×10^8	4.99×10^8
Operational costs of DG (Rs)	2.49×10^8	2.495×10^8
Maintenance cost of DG (Rs)	6.34×10^7	6.342×10^7
Maintenance cost of Capacitor (Rs)	2.45×10^5	1.8988×10^5
Total profit of DISCOs (Rs)	2137.19×10^5	**2151.40×10^5**

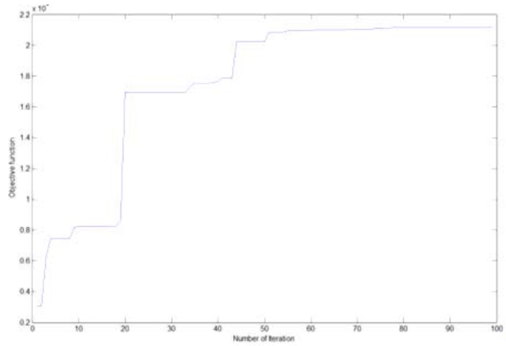

Fig. 8. Convergence curve of in 69-node test system

The proposed technique also analyzes the cost-benefit of DISCOs and DG owners in a competitive electricity market. The obtained values are clearly reported in Table 5. In this table, Installation cost of DG and capacitor is 375 x 10^5 and 10.5 x $10^{4.}$ Benefits obtained from loss reduction and purchased energy is 6.684 x $10^7$and 4.99 x $10^{87.}$respectively. Operational costs of DG are 2.495x$10^{8..}$ Maintenance cost of DG and Capacitor is 6.342 x 10^7 and 1.8988 x 10^5 respectively. The maximized profit computational time of DISCOs by proposed ALO algorithm is Rs. 2151.4x 10^5 and 48.5 sec. The convergence curve of in 69-node test system is graphically displayed in figure 8. The numerical results obtained from this method are compared with PSO method and are given in Table 6. In this table, the proposed method has minimum installation and maintenance cost of capacitor compared with PSO method. Similarly, benefit and profit of DISCOs are effectively improved by best configuration with optimal placement of DG and capacitor in a proper manner.

Conclusion

An approach based on MFO technique has been presented in this paper to improve the profit margin of distribution companies. It has been accomplished through the process of reconfiguration of existing networks and proper placement and sizing of capacitor banks and DGs. The proposed methodologies effectively reduce the line losses and thereby boost the benefits of the DGs owners. Moreover, it also saves various types of cost such as investment and operational cost by selling the power recovered from the minimized line losses. The test studies were carried out on standard IEEE 33 and 69-node systems. The experimental results show that the proposed MFO algorithm is a promising approach for improving the profit margin of distribution companies.

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