Simultaneous optimization of transformer tap changer and network capacitors to improve the distribution system's static security considering distributed generation sources

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Simultaneous Optimization of Transformer Tap Changer and Network Capacitors to Improve the Distribution System's Static Security Considering Distributed Generation Sources

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Abstract:
Voltage control and reactive power play an important role in the operation of the distribution network. Accordingly, conventional methods such as the installation of a capacitor in an optimum location with a proper capacity and optimal transformer tap setting which has an impressive effect on voltage control and reactive power are used. But the study on the simultaneous use of these two methods is limited and it seems necessary to be conducted. These days the presence of Distributed Generation (DG) resources has grown in distribution networks. The presence of distributed generation resources has a great influence on the voltage profile due to the radial structure of the distribution network and the low X/R ratio. Therefore, it is necessary to consider the optimal coordination of the use of switchable capacitors and the setting of transformer taps in the presence of distributed generation resources to improve the voltage profile and reduce losses. This paper examines the simultaneous use of capacitors and transformer taps in distribution networks to reduce the voltage deviation and distribution losses in the presence of distributed generation resources. In order to explain the objectives, six different operation scenarios have been defined and studied. The above study is implemented based on the IEEE, 13 and 34 bus standard networks and the results are presented. The presented results clearly indicate the necessity of coordinating the use of these tools in distribution networks.

Keywords: Capacitor, Distributed Generation Resources, Loss Reduction, Particle Swarm Optimization Algorithm, Transformer Tap Changer, Voltage Adjustment.

I. INTRODUCTION

One of the important issues in optimal operation of electricity distribution systems is to reduce losses and improve the voltage profile. Given the presence of control devices such as capacitors, synchronous condensers various types of flexible ac transmission systems (FACTS) controllers and Continuously Variable Series Reactor (CVSR), transformers with Under Load Tap Changer (ULTC), the distribution systems are capable of controlling voltage and reactive power and thus reducing losses, and improving the voltage profile [1]. The main purpose of the study and the verification of voltage and reactive power control is to regulate and correctly coordinate these control devices in the distribution substations and feeders. ULTC adjusts the output voltage by changing the number of windings in the transformers. The switchable capacitors installed on the substation or on the feeders, control the reactive power passing through the bulk power substation and distribution feeders by switching CVSR, a series variable reactor that has variable reactance can control a voltage on the ac side by changing the dc bias current [2]. The problem of optimal reactive power planning is one of the important issues in the power grid. The purpose of reactive power planning is to provide sufficient reactive source in the power system and achieve the desired goals including the reduction in losses, minimizing investment costs and reducing voltage deviations, etc. in normal operation or in case of potential network failure based on a series of constraints. Therefore, the problem of reactive power planning can be expressed as an optimization problem, which includes the objective function and the related constraints.

Today, the distributed generation resources are widely used in electric systems which has driven the grids more complex than before [3]. This results in considering more control actions. Although, distributed generations are small quantities of energy resources that generate energy at the place of consumption and supply them to the consumer. These resources are easily installed in different parts of the distribution network and do not suffer from the problem with large power plants to find the location of the installation [4, 5]. In distribution companies, the problem of voltage and reactive power control in distribution networks aimed at minimizing voltage deviation and losses, correcting of voltage profile on all feeders and modifying power factor can be solved using the transformers with ULTC and capacitors, and CVSR [6, 7]. So far, studies on voltage and reactive power control in distribution systems have been done regardless of the effect of distributed generation units. Given the extent of the problem space, most studied seek to find a method to achieve the best response in the shortest time. In [8], an effective combined approach is presented for controlling the voltage and reactive power in distribution systems by changing the constraints on the taps and capacitors. The proposed method is a combination of the gradient method and a meta-heuristic technique. In [9], a mixed integer linear programming model is proposed to optimize controlling voltage and reactive power in an unbalanced distribution feeder with a three-phase medium voltage level. In the optimization, it is assumed that there is a ULTC and reactive distributed generation resources in the network.

In [10], the total harmonic distortion /volt / var control in distribution networks is presented in the presence of reactive power of solar energy. The main objective of this study is to find a suitable program for capacitors' dispatching, ULTC tap changer position and inverter based reactive power of photovoltaic systems based on the power quality constraints. In [11], the multi-objective daily volt/var control is presented in the presence of distributed generation units. The main objective of this study is to determine the optimal dispatching for ULTC and shunt capacitors based on the next day load prediction. In [12], fuzzy optimization is used to control the voltage and reactive power in the distribution system. Although most studies focus on optimizing distribution network losses and voltage profiles, a small number of researchers have considered the optimal performance of capacitors and transformers in their target functions which is addressed in this study.

In [13], using a two-stage neural network, an expert system has been used to real time control of the stepped capacitors installed in the distribution system with a non-uniform load curve to reduce losses. The input data is directly provided by the online measurements including active and reactive power of lines, voltage measurements and current position of capacitor taps. In order to solve the multi-objective voltage and reactive power control problem, the fuzzification of the objective and constrain functions and the Simulated Annealing algorithm are used to determine the final solution. In [14], the control of the capacitors installed on a feeder has been investigated in terms of daily operation. The goal is to achieve an optimal capacitor strategy based on the hourly load forecast for the next day, so that the total feeder losses over a day are minimized. Constraints to be met include: the maximum number of switching operations per capacitor during a day and the voltage drop across the feeder. A dynamic programming approach is proposed to achieve this optimal strategy. In [15], the dynamic-fuzzy programming is used to solve the voltage and reactive power control problem in a bulk power substation. The main goal is to improve the voltage profile in the secondary bus and limit the power transfer to the transformer. In order to achieve this goal, ULTC transformer is used to adjust the secondary voltage and the capacitor is used in the secondary bus to compensate for the reactive power of the load. First, the active and reactive power of the transformer and its initial voltage are predicted for the next day. Using these data, to reduce the calculation, a method which considers the load model is used to quickly estimate the tap position. The constraints include the bus voltage limitation, the maximum number of switching for capacitor and tap changer in one day and the worst power factor for a transformer.

[16, 17] solved the voltage and reactive power control problem considering the feeder losses and voltage drop constraints by fuzzy algorithm and dynamic programming. In [4] and [18], only the feeder capacitors are used in the optimal control of voltage and reactive power while the substation capacitors and ULTC are not considered. In [19], to reduce the search space, a time-based method and a 24-hour load prediction were used to determine the tap position at each time interval and the genetic algorithm is applied to determine the optimal response. In [20, 21], a hybrid algorithm is proposed to optimize reactive power by considering load changes in distribution systems. Considering the extensive presence of the distributed generation resources and their impact on the distribution network, studies have been done in this area, some of which are briefly discussed. [22] presented simultaneous optimization of the location of distributed generation resources, fixed and switchable capacitor banks, and network reconfiguration in the distributed systems using genetic algorithm at different load levels. Using this algorithm, optimal distribution network reconfiguration and the optimal location of distributed generation resources and capacitor banks are achieved. The objective function includes the cost of real losses, the cost of investment and the setting up of distributed generation units, the cost of installing fixed and switchable capacitor banks, and the cost of purchasing the true consumed power from the upstream network which is reduced by this algorithm.

In [23], a random multi-objective framework is proposed for multi-objective daily volt/var control through considering the dispersed generation resources including water turbines, fuel cell, wind turbine and photovoltaic cells using a learning based optimization algorithm. Goals are defined as controlling voltage and reactive power, reducing electric power losses, reducing voltage deviations, reducing electricity generation costs and reducing greenhouse gas emissions from renewable energy sources and distribution networks. In [24], the improved shuffled frog leaping algorithm is applied for multi-objective probabilistic voltage control problem in the presence of renewable energy sources. The objective functions that have been investigated include reducing the cost of producing electricity by wind farms and fuel cell power plants, reducing electricity losses and greenhouse gases. In [25], the problem of voltage and reactive power control is discussed in the presence of the induction machine type (wind turbine) distributed generation resources using local and central control of equipment. The feeder capacitors are controlled via a local type of voltage controller but the substations capacitors and ULTC transformers are capable of remote control and are controlled based on daily load prediction.

In [26], voltage and reactive power controls are carried out in the presence of synchronous generator based distributed generator and it is assumed that all equipment has only local control capability. In [27], a new algorithm called HBMO is provided for daily volt/var control in the distribution system at the presence of DG resources. Control objectives include reducing energy production costs by distribution companies and distributed generation sources, electricity losses and voltage deviations in the next day. In [12], a fuzzy volt/var control is presented in a distribution system with uncertainty. The main goal is to achieve an appropriate dispatching program for the ULTC tap position of the transformer and parallel capacitor in the substation and parallel capacitor in the feeder which minimizes losses and reactive power transfer through the transformer and improves the voltage profile.

The above cases present the role of instruments such as transformers with Tap changer, capacitors, and distributed generation resources in controlling and improving the voltage profile and reducing the active power loss of the distribution system. The use of the above tools is rapidly expanding in today's distribution systems. Coordinated application of this tool can lead to more optimal results. Here the necessity of coordinated use of this tool in the distributed network is discussed.

II. VOLTAGE VARIATION IN THE DISTRIBUTION NETWORK

The flow of the active and reactive power is always from a higher voltage level to a lower one [28]. The value of the voltage drop can be calculated by the analysis of 2-bus distribution system shown in FIGURE 1.

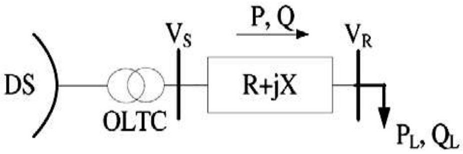

FIGURE 1
SAMPLE DISTRIBUTION NETWORK WITH 2-BUS LOAD

The voltage drop between the sender and receiver sides is obtained by the following equation:

$$\Delta V = \frac{RP + XQ}{Vs} \tag{1}$$

VOLTAGE CHANGES IN THE DISTRIBUTION NETWORK WITH DISTRIBUTED GENERATION RESOURCE CONNECTION

When generators connect to the distribution network, the power flow and voltage profiles will be affected. In order to transfer power, a generator is likely to work at higher voltages compared to other buses [29].

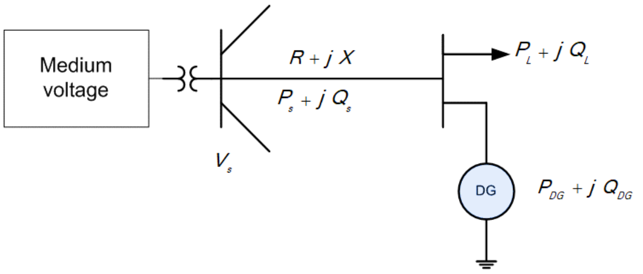

FIGURE 2
CONNECTING A DISTRIBUTED GENERATION SOURCE TO THE LOAD BUS

In this case, according to **FIGURE 2**, the voltage drop is calculated as follows:

$$\Delta V = \frac{R(P_L - P_{DG}) + X(Q_L - Q_{DG})}{Vs} \tag{2}$$

Where PDG and QDG are the active and reactive power injected to the bus.

CONTROL OF CHANGES IN REACTIVE POWER AND VOLTAGE IN DISTRIBUTED NETWORKS AT THE PRESENCE OF DISTRIBUTED GENERATION RESOURCES

If in the peak hours the injected power of DG is less than the load power, ΔV will be positive and therefore DG acts to improve the voltage profile and to approach the bus voltage to the substation voltage. However, if during the minimum load the injected power of DG is greater than the load power, ΔV will be negative and therefore the bus voltage will exceed the substation voltage which means that it suffers from overvoltage. To deal with overvoltage caused by the DG resource, the distribution transformer's tap should be reduced and remove other reactive power compensators; In this case, the following problems may occur:

A. At maximum load the voltage of the end of the feeder will drop excessively when the DG is out of the service (due to the change in the tap or removing the reactive power compensators). This state should be studied in a scenario without DG resources and maximum network loading.

B. Due to reduced transformer tap, other feeders will be problematic. In this case, other feeders should also be check if at the maximum network load they are having trouble by changing the tap or not.

Thus based on what has been discussed above, the necessity of coordination between switchable capacitors and the position of the transformer tap in the presence of DG resources to improve the voltage profile and reduce the losses is specified and it is evident that it is a complex task.

OBJECTIVE FUNCTIONS

The purpose of this paper is to minimize bus voltage deviation, network losses, and the cost of reactive power generation, along with the determination of the status of voltage control and distributed resource devices. Therefore, the objective functions are defined as the following equations [1]:

I. Voltage Deviation

$$VD = \sum_{i=1}^{n} |V_{i,ref} - V_i| \tag{3}$$

II. Losses

$$LOSS = 3\sum_{i=1}^{n} RI^2 \tag{4}$$

III. Cost

The cost of reactive power generation is calculated after each load flow. This cost is the same as the cost of the capacitance in the network, which is defined as follows:

$$\cos t = (Ms.\, Cis) + \sum_{i=1}^{n} (Cvs.\, Qsi) \tag{5}$$

Ms: Number of switchable capacitors installed on the network, *Cis:* Cost of switchable capacitors, *Cvs:* Cost per KVar of switchable capacitor and *Qsi:* The amount of switchable capacitor installed on the bus *i*.

IV. General Objective Function

$$\min z = (k1.VD + k2.LOSS + k3.\cos t) \tag{6}$$

k1, *k2*, and *k3* are the weight coefficients that are selected according to the view of the operator and the current network conditions. Therefore, considering the importance of voltage profile in comparison with other criteria, the weight coefficients of *k1* = 0.6, *k2* = 0.1 and *k3* = 0.3 are considered.

PROBLEM CONSTRAINTS

In each optimization problem in addition to the objective function, the constraints are considered as well. The constraints of this problem include:

I. Bus Voltage Range

$$Vi,\min \le Vi \le Vi,\max \tag{7}$$

$V_{i,min}$ and $V_{i,max}$ are the minimum and maximum bus voltage ranges (minimum=0.9 per unit, maximum=1.05 per unit).

II. Transformer Tap Switching Range

$$Tap_i^{\min} \le Tap_i \le Tap_i^{\max} \tag{8}$$

$Tapi^{min}$ and $Tapi^{max}$ are the minimum and maximum transformer tap positions. The voltage change level for each tap step is between 1 and 2.5% and the number of steps in the distribution transformers is 2, 3, or 5 steps but this number reaches up to 30 steps in power transformers.

III. Distributed Generation Resources' Range

$$Pgi,\min \le Pgi \le Pgi,\max \tag{9}$$

Pgi,min and *Pgi,max* are the minimum and maximum real power produced by the DG resource.

III. DG RESOURCES MODELING

In general, DG resources that are connected to distribution networks because of their small production capacity cannot be considered similar to the centralized power plants in which the connected bus was always considered as PV bus. Therefore, the DG resources are divided into two groups in terms of exploitation in distribution networks [30]:

AS A PV MODEL

In the DG simulation as a PV model, the generator delivers the network a constant voltage under a given phase angle. In this case, the task of the energy production source is to maintain the bus voltage range within the allowed range. This happens when the DG resource can be able to provide reactive power to the bus.

AS A PQ MODEL

In the DG simulation as a PQ model the power generator injects a certain active and reactive power into the network or uses DG units in a constant power factor. This modeling is similar to the modeling of constant power loads with the difference that the current is injected into the bus. In this case, the DG resource's task is to feed the network and provide part of the active and reactive power required by it. This state occurs when the generator cannot generate reactive power. In this paper, distributed generation is considered as a PQ model.

IV. METHOD FOR DETERMINING THE LOCATION AND OPTIMAL AMOUNT OF DISTRIBUTED GENERATION RESOURCE

In a distribution network, the power loss curve is almost a quadratic function because the line losses are proportional to RI^2 and I is proportional to S and it is assumed that I is the line current and S is the apparent power transferred through the line [31]. Therefore, if the DG size increases in the desired location, the losses reach their lowest value due to lower flow of current to the desired feeder. With continued increase in the DG capacity, the losses will increase again. This process of losses vs. the DG size variations is shown in Figure 3.

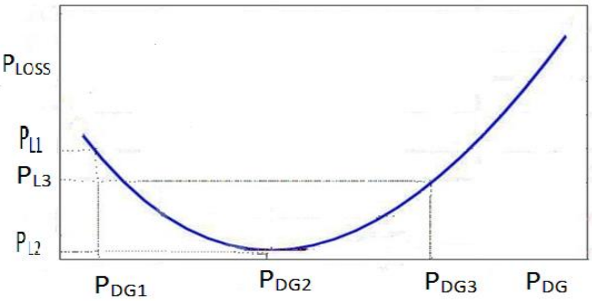

FIGURE 3
LOSSES VS. THE DG (ACTIVE POWER) SIZE VARIATIONS

The two indices of loss reduction and improvement of voltage profile are used to determine the optimal location and DG size.

I. Loss Reduction Index

$$LossI = \frac{Loss_{W/DG}}{Loss_{WO/DG}} \tag{10}$$

Where $Loss_{W/DG}$ is the system losses in the presence of distributed generation resource and $Loss_{WO/DG}$ is the system losses in the absence of distributed generation resource.

II. Voltage Profile Improvement Index

$$VPI = \frac{V_{PW/DG}}{V_{PWO/DG}} \tag{11}$$

Where, $V_{PW/DG}$ is the network voltage profile in the presence of distributed generation resource and $V_{PWO/DG}$ is the network voltage profile in the absence of distributed generation resource. To determine the optimal location and size of the DG resource by these two indices the following objective function is considered by giving weight coefficients (in this paper, $K1 = K2 = 0.5$).

$$F = K1.LoosI + K2.VPI \tag{12}$$

To determine the optimal location for installing DG, a feed source with the minimum value of 100 kilowatts is considered in the network buses and the indices and the function F are calculated. In each bus the least value of which is F, that bus is chosen as the optimal location for the DG resource installation with a specified value. To calculate the optimum size of the DG resource the losses and voltage deviations are calculated then the DG resource values is increased in the 100 kilowatt steps to the extent that the loss amount does not increase for increasing the DG. The maximum amount selected for DG size is the total load of the network [32, 33]:

$$0 \le P_{DG} \le \sum_{i=1}^{NB} Pi \tag{13}$$

Where NB is the total number of buses and p_i is the consumed load per bus.

V. SENSITIVITY ANALYSIS AND DETERMINATION OF LOSS SENSITIVITY FACTOR

A new method for determining the candidate buses to install the capacitor is to use the loss sensitivity factor. Using this technique reduces the search space and increases the speed of convergence of optimization algorithms. By assuming a distribution line between the p and q buses as shown in **FIGURE 4**, the active power losses in the line k is as defined as follows [34, 35]:

$$P_{line-Loss}[q] = \frac{(P_{eff}{}^2[q] + Q_{eff}{}^2[q])R[K]}{V^2[q]} \tag{14}$$

P_{eff} is the total active power consumption at node q and nodes after node q, Q_{eff} is the total reactive power consumed in node q and nodes after node q and $R\ [K]$ is the line k resistance. Now, the loss sensitivity factors are obtained according to (15) for all lines by deriving the loss function in terms of Q_{eff}.

$$\frac{\partial P_{Line-Loss}}{\partial Q_{eff}} = \frac{2.Q_{eff}[q].R[K]}{V^2[q]} \tag{15}$$

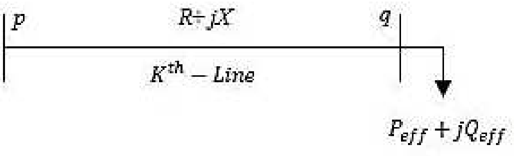

FIGURE 4
Distribution Line Model Between Buses p and q

The loss sensitivity factors are calculated by performing load flow using (15) for all branches of the studied system. The voltage magnitude of all prioritized buses obtained by performing the load flow are first calculated in per unit based on base voltage of the network and then divided by 0.95 (the lower limit of the permitted voltage). The buses with the calculated number of less than 1.01 are selected as the candidate buses for installing capacitor banks for the optimization program. Therefore, using this method, the selected compensating buses, firstly, had the most effect in reducing the total network losses and secondly their voltage is lower than the limit before executing the compensation algorithm. After selecting the candidate buses to install the capacitor, the optimization algorithm is used to determine the exact location as well as the optimal capacitors in order to achieve the goals and constraints of the problem.

VI. Simulation by Applying the Particle Swarm Optimization Method

In this research the particle swarm optimization algorithm (PSO) is used for simultaneous optimization of the capacitor banks and tap changer in the presence of distributed generation resources to reduce losses and voltage deviations. The reason for using this method is the efficiency, simplicity and successful experience of using it in similar problems. The steps for using the PSO algorithm are as follows:

i. The initial position and velocity of particles are generated randomly in the permissible range. (Primary population generation)
ii. Load flow implementation
iii. P_best for each particle is considered as equal to its original position (in the first iteration). Also, g_best i.e. the best particle among particles is selected based on fitness in the objective functions (losses, voltage deviation and cost)
iv. The new speed and position of each particle are calculated by relations (16) and (17):

$$Vd(t+1) = W.Vd(t) + C1.rand(0,\phi_1)(P_{i,d} - Xd(t)) + C2.rand(0,\phi_2)(P_{g,d} - Xd(t)) \tag{16}$$

$$x(t+1) = x(t) + Vd(t+1) \tag{17}$$

rand function generates random number between [0,1]. C1 and C2 are called the impact constants. W is the inertia parameter added to the algorithm in order to provide a better search functionality.

v. The objective functions are calculated for each particle.
vi. If the values of the new objective functions for each particle are better than their value in P_best, it will be replaced and similarly, if in the whole new population a better particle is found in terms of the degree of suitability in the objective functions, g_best is replaced.
vii. Steps 4-7 are performed to reach the maximum number of iterations (maxit).

Simulation Conditions

FIGURE 5 shows the IEEE 13 Node Test Feeder system. The base voltage of this network is 24,900 volts and the total load consumption is 3466 kilowatts. FIGURE 6 illustrates the IEEE 34 Node Test Feeder system with a 24900V base voltage and a total network load of 1769 kW. In this paper, these two systems are used to perform simulations. Simulation conditions are as follows:

1. Particle swarm optimization algorithm Parameters in problem solving:
   - The number of particles (n=50)
   - The importance of the best particle (C1 =2)
   - The importance of the best neighborhoods (C2=2)
   - Weight of inertia to create better search capability (W=1)
   - The number of iterations (maxit =100)
   - *nvar*: The number of candidate buses for the installation of capacitor.
   - The technical information of the13-bus network is referenced in [35] and the technical information of the 34-bus network is given in reference [36].
2. Capacitor banks consist of ten 100 kW steps that after load flow, sensitivity analysis and using PSO algorithm their optimum location and sizes are obtained.
3. The ULTC transformer has a 5 positions that the best position of which is obtained by particle swarm optimization algorithm.
4. The optimum location and amount of PQ distributed generation resources is obtained using loss reduction and voltage profile indexes.
5. Three levels of load are considered for these networks. **FIGURE 7** shows the plotted graph of load variations and the duration of each one.

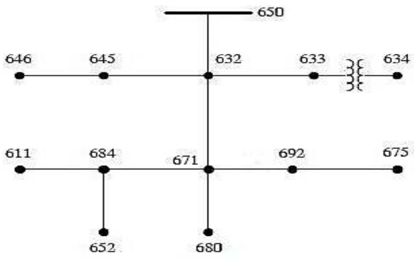

FIGURE 5
IEEE 13 Node Test Feeder System

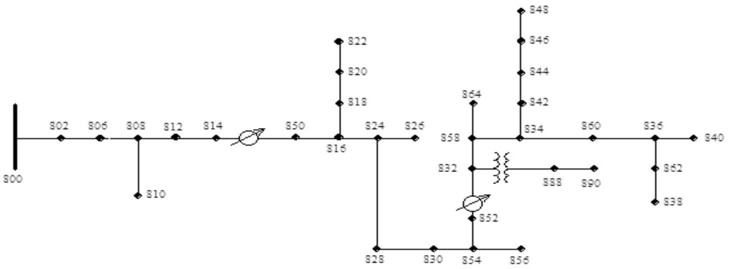

FIGURE 6
IEEE 34 Node Test Feeder System

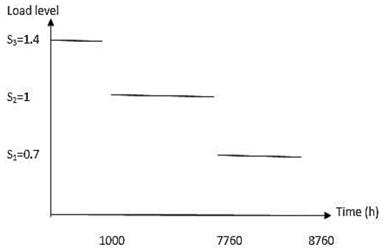

FIGURE 7
PLOTTED GRAPH OF LOAD VARIATIONS

OPTIMAL LOCATION AND AMOUNT OF DISTRIBUTED GENERATION RESOURCE

Using the analytical method presented in Section 4, the optimal location of the distributed generation resource in 13-bus network is the bus 671 and its optimal size is 2800 kW. Also the optimum location of the distributed generation resource in the 34- bus network is the bus 834 and its optimal size is 800 kW.

CAPACITOR CANDIDATE BUSES USING SENSITIVITY ANALYSIS

Using the sensitivity analysis (Section 5), the buses that are more sensitive to reactive power injections and are candidates for the installation of capacitor are presented in Table I and Table II for the two networks.

TABLE I
LOCATION OF CANDIDATE BUSES FOR THE INSTALLATION OF CAPACITOR IN 13-BUS NETWORK

Bus No.	611	652	671	675	680	684	692

VII. SIMULATION RESULTS

Examining different states in 13 and 34-bus standard networks. Regarding the consideration of three different levels of load during the year in two standard networks, six scenarios are considered as follows:

1. Optimization of the location and amount of capacitor banks (1st scenario)
2. Optimization of the tap changer position (2nd scenario)
3. Optimization of the location and amount of capacitor banks and tap changer position simultaneously (3rd scenario)
4. Optimization of the location and amount of capacitor banks in the presence of DG resource (4th scenario)
5. Optimization of tap changer position in the presence of DG resource (5th scenario)
6. Optimization of the location and amount of capacitor banks and tap changer position simultaneously in the presence of DG resource (6th scenario)

In Table 3and Table 4 the optimal location and amount of capacitor banks are obtained by loss sensitivity analysis and PSO algorithm for the two standard 13 and 34-bus systems.

It should be noted that since in the 2nd and 5th scenarios the optimization of capacitor banks is not discussed, these scenarios are not considered in Table 3 and Table 4.

In Table 5and Table 6, the optimal position of the transformer tap changer is presented in two standard 13 and 34 bus networks, taking into account the different load levels for the relevant scenarios. The tap changer is located between the buses 633 and 634 in the 13-bus network and between the buses 832 and 888 in the 34-bus network.

The normal tap in the transformer tap changer is 3 (, n is the number of transformer taps i.e. in this tap the percentage of voltage given to the voltage output is zero. For example, in Table 4, when it is said that the optimal position of the tap in the average load level (0.7) in the 2nd scenario is equal to 4, it means that the voltage percentage added to the output voltage is 2.5% (1.025). By applying different scenarios and at 3 desired levels, the losses are given in kilowatt and the voltage deviation is calculated in per unit and presented in Table 7and Table 8.

TABLE II
LOCATION OF CANDIDATE BUSES FOR INSTALLATION OF CAPACITOR IN 34-BUS NETWORK

bus No.	820	822	832	834	836	838	840	842	844
bus No.	846	848	852	858	860	862	864	888	890

TABLE III
THE LOCATION AND OPTIMAL AMOUNT OF CAPACITORS (KVAR) UNDER DIFFERENT LOAD CONDITIONS IN 13-BUS NETWORK

Bus No.	Load level	Scenario 1	Scenario 3	Scenario 4	Scenario 6
611	0.7	100	100	100	100
	1	100	100	100	100
	1.4	100	100	100	100
652	0.7	100	100	100	100
	1	100	100	0	100
	1.4	100	100	100	100
671	0.7	100	100	100	100
	1	100	100	100	100
	1.4	100	100	100	100
675	0.7	100	100	100	100
	1	100	100	100	100
	1.4	100	100	100	100
680	0.7	0	0	0	0
	1	0	0	0	0
	1.4	0	0	0	0

684	0.7	100	100	100	100
	1	100	100	100	0
	1.4	100	100	100	100
692	0.7	100	100	100	100
	1	100	100	100	200
	1.4	100	100	100	100

TABLE IV

THE LOCATION AND OPTIMAL AMOUNT OF CAPACITORS (KVAR) UNDER DIFFERENT LOAD CONDITIONS IN 34-BUS NETWORK

Bus No.	Load level	Scenario 1	Scenario 3	Scenario 4	Scenario 6
820	0.7	100	100	0	100
	1	100	0	100	100
	1.4	100	100	100	100
822	0.7	0	0	0	0
	1	0	0	0	0
	1.4	0	0	0	0
832	0.7	100	100	0	100
	1	100	0	1000	0
	1.4	100	100	100	100
834	0.7	100	100	1000	100
	1	100	0	100	0
	1.4	100	0	100	100
836	0.7	100	100	0	0
	1	100	100	100	0
	1.4	100	0	100	100
838	0.7	0	0	0	0
	1	0	0	0	0
	1.4	0	100	100	0
840	0.7	0	0	0	0
	1	0	0	100	0
	1.4	100	0	100	100
842	0.7	100	100	0	0
	1	100	0	100	0
	1.4	100	0	0	100
844	0.7	100	100	0	100
	1	100	0	100	0
	1.4	100	0	100	300
846	0.7	0	100	0	100
	1	100	100	0	0
	1.4	100	0	100	0
848	0.7	0	0	0	0
	1	0	0	100	0
	1.4	0	0	0	100
852	0.7	0	0	0	0
	1	100	0	0	0
	1.4	0	0	0	0
858	0.7	0	0	0	0
	1	0	0	100	100
	1.4	0	0	100	0
860	0.7	0	0	0	100
	1	100	0	100	1000
	1.4	100	0	100	0
862	0.7	0	0	0	100
	1	0	0	0	0
	1.4	0	0	0	0
864	0.7	0	0	0	0
	1	0	100	0	100
	1.4	0	0	0	0
888	0.7	100	100	0	100
	1	100	0	100	100
	1.4	0	0	0	0
890	0.7	100	500	400	200

1	100	500	100	500
1.4	100	500	300	600

TABLE V
OPTIMAL TRANSFORMER TAP POSITION IN 13-BUS NETWORK

Position Tap	Scenario	Load level
2	2	0.7
2	3	
2	5	
2	6	
2	2	1
2	3	
2	5	
2	6	
2	2	1.4
2	3	
2	5	
2	6	

TABLE VI
OPTIMAL TRANSFORMER TAP LOCATION IN 34-BUS NETWORK

Position Tap	Scenario	Load level
4	2	0.7
2	3	
3	5	
2	6	
5	2	1
4	3	
4	5	
2	6	
5	2	1.4
4	3	
5	5	
2	6	

TABLE VII
RESULTS OF SIMULATION IN 13-BUS NETWORK

Voltage Deviance (p.u)	Loss (kW)	Scenario	Load level
0.0060439	48.548	1	0.7
0.074782	49.24	2	
0.0041596	40.46	3	
0.000047167	13.353	4	
0.11321	20.758	5	
0.000029708	11.281	6	
0.013409	101.73	1	1
0.0592	98.457	2	
0.0092679	85.142	3	
0.0014998	21.652	4	
0.092823	32.558	5	
0.00104	17.961	6	

0.027267	200.8	1	1.4
0.042482	187.85	2	
0.018949	168.97	3	
0.0072838	59.298	4	
0.069828	73.208	5	
0.005373	52.876	6	

TABLE VIII
RESULTS OF SIMULATION IN 34-BUS NETWORK

Voltage Deviance(p.u)	Loss(kw)	Scenario	Load level
0.0060439	48.548	1	0.7
0.074782	49.24	2	
0.0041596	40.46	3	
0.000047167	13.353	4	
0.11321	20.758	5	
0.000029708	11.281	6	
0.013409	101.73	1	1
0.0592	98.457	2	
0.0092679	85.142	3	
0.0014998	21.652	4	
0.092823	32.558	5	
0.00104	17.961	6	
0.027267	200.8	1	1.4
0.042482	187.85	2	
0.018949	168.97	3	
0.0072838	59.298	4	
0.069828	73.208	5	
0.005373	52.876	6	

In Figure 8 to Figure 11, the voltage profiles for the two standard 13 and 34-bus networks are shown from non-compensation to 6th scenario modes.

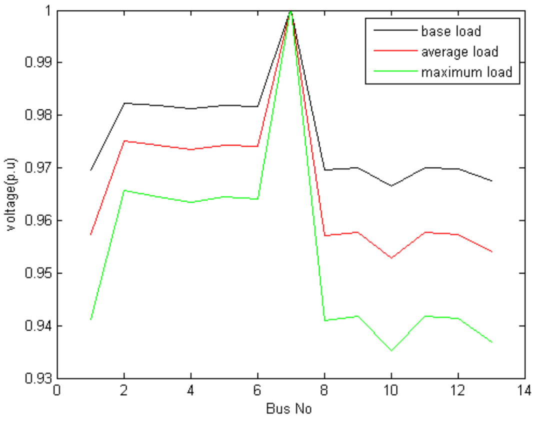

FIGURE 8
VOLTAGE PROFILE OF 13-BUS NETWORK AT DIFFERENT LOAD LEVELS WITHOUT COMPENSATION

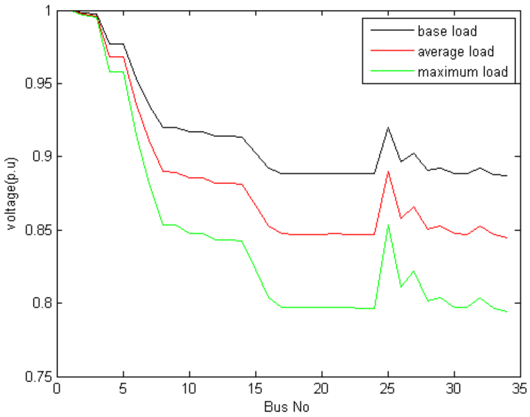

FIGURE 9
VOLTAGE PROFILE OF 34-BUS NETWORK AT DIFFERENT LOAD LEVELS WITHOUT COMPENSATION

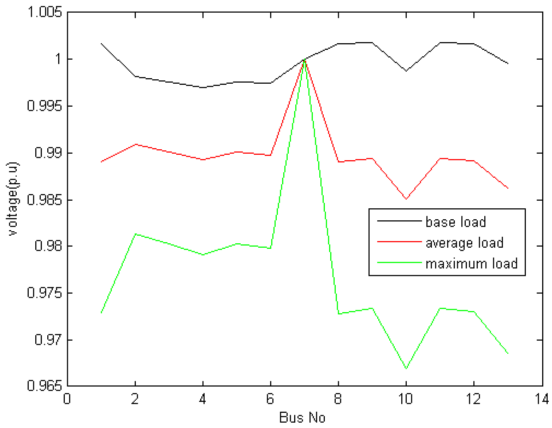

FIGURE 10
VOLTAGE PROFILE OF 13-BUS NETWORK AT DIFFERENT LOAD LEVELS WITH CAPACITOR INSTALLATION AND TAP CHANGER IN THE PRESENCE OF THE DG RESOURCE

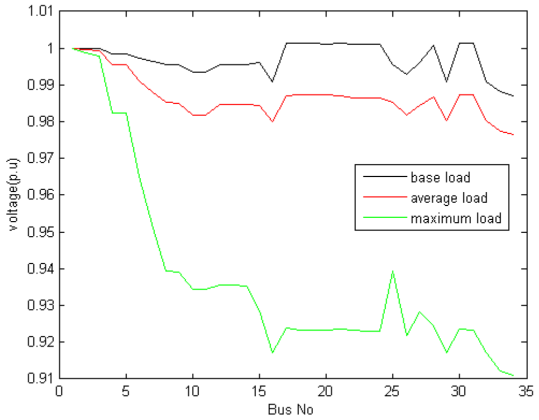

FIGURE 11
VOLTAGE PROFILE OF 34-BUS NETWORK AT DIFFERENT LOAD LEVELS WITH CAPACITOR INSTALLATION AND TAP CHANGER IN THE PRESENCE OF THE DG RESOURCE

VIII. CONCLUSIONS

This paper examined the simultaneous use of capacitors and transformers with tap changers in the presence of DG resources to control voltage / reactive power and reduce losses. It has been shown that coordination in the utilization of these tools in the distribution network is very important and can lead to better performance. In order to examine the results of this work six scenarios have been defined to determine the effectiveness of this method by comparing the indices. On the other hand, in order to make the simulation more realistic, considering the load variability, three different load levels were considered. It is concluded from the simulation of applying different scenarios that coordination in the use of the above tools reduces the number of buses whose voltages are below the lower limit at different load levels to the point that in the 6th scenario and in coordination between the capacitors, the tap changer and the DG resource reached the minimum level. Also, in terms of reducing the losses and voltage deviation, the best mode is associated with the 6th scenario i.e. when the optimal location and value of the capacitor banks is coordinated with the optimal position of the transformer tap changer in the presence of DG resources.

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