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A new method to reduce the adverse effects of wind power on power quality using reactive power compensating capacitors

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Abstract: The usage of distributed generation resources, particularly distributed generation with renewable sources, has increased to generate electrical power close to consumers. One of the factors that can reduce penetration of distributed generation resources is the limitation of power quality, such as harmonic distortions. Distributed generation sources, in addition to producing power, due to using of power electronic converters and changing the power flow, increase harmonic currents. On the other hand, local compensation of reactive power by parallel capacitor banks is one of the effective methods to reduce power system losses and harmonic distortions. Since the capacitor impedance varies at different frequencies and resonance can be produced at harmonic frequencies, providing an efficient method to optimize capacitor banks' placement in the presence of nonlinear loads and distributed generation is important. In this paper, first the adverse effects of distributed generation on power system harmonic distortions and therefore on power quality are illustrated by experiments. The problem of the optimal capacitor placement in the presence of nonlinear loads and distributed generation (wind power) is then expressed as a fuzzy multiobjective model. In the proposed model, annual profit maximization resulting from loss reduction, bus voltage deviation minimization, and reduction of power system harmonics are considered as optimization objectives. The presented model is solved with a PSO algorithm and a special version of the backward-forward sweep considering the system harmonics. Efficiency of the proposed model is demonstrated by running experiments on an 18-bus IEEE distributed network.

Key words: Capacitor placement, distributed generation, multiobjective optimization, nonlinear load, power quality

1. Introduction

Using new and sensitive electrical equipment, which requires high-quality power and on the other hand is an origin of destructive power quality phenomena, has caused power quality to become a serious concern of electrical companies and consumers recently. One important aspect of power quality is the presence of harmonics in the power system, causing adverse effects such as increasing losses in the power system. Furthermore, with the increasing use of distributed generation resources, particularly renewable energies whose variable nature causes harmful effects on the network power quality, power quality issues have been attracting more interest [1]. Capacitor banks were used widely in distribution networks for local reactive power compensation traditionally in order to meet some goals such as reducing energy losses, improving voltage deviation, releasing line capacity, improving power factor, and, recently, improving power quality. The importance and economical benefits of optimal capacitor placement has stimulated many researchers to propose and research various analytical and innovative models [2,3]. These include solving the problem by dynamic programming approach [4], innovative

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methods such as heuristic algorithms [5,6], genetic algorithms [7–10], simulated annealing [11,12], and tabu search [13,14].

The increasing use of nonlinear loads such as in power electronic devices and household and electromagnetic appliances injects a sgnificant amount of harmonic currents. Moreover, distributed generation resources, particularly renewable energies, add significant amounts of harmonic currents to the network due to their variable nature and supplying power via power electronic converters. Since the impedance of capacitors changes at different frequencies (harmonic frequencies) [15], if the location and the size of capacitors are not selected properly there will be a possibility of resonant circuits occurring and thereby the amount of harmonic voltage and current will be increased [15]. Therefore, capacitor placement should be done considering harmonics in order to prevent boosting harmonic currents by capacitor banks. Considering the importance of nonlinear loads, the capacitor placement problem has been studied [16–18]. Most of methods that were presented for solving this problem assumed a network in sinusoidal mode and neglected the coupling between the lines' impedance at harmonic frequencies. The problem was modeled in terms of economic goals and power quality parameters were investigated as constraints after locating the capacitors.

In the capacitor placement problem, reducing the investment costs associated with the installation and maintenance of capacitor banks is in contrast with improving power quality. However, the importance of providing customers with high-quality electric power motivated electric companies to improve power quality. Using multiobjective optimization provides interaction between the objects of the problem, considering the designer's point of view.

Although optimal capacitor placement is a common and conventional method and many relevant studies have been done, they were conducted in the presence of insignificant wind power. For example, [19–25] are samples of investigating capacitor placement in the presence of distributed generation, but these papers did not distinguish the kind of distributed generation and did not survey power quality as such. In this paper, first harmful effects of distributed generation on system power quality are shown by applying several experiments. The necessity of special attention to nonlinear loads and distributed generation in the process of capacitor placement is then evaluated in order to achieve loss reduction and improve power quality. Capacitor banks are used to enhance power quality. To this end, a fuzzy approach is presented to express and implement capacitor placement with a multiobjective method, where the objective function is composed of 3 parts: maximizing annual profit of capacitor installation (including energy loss reduction and reducing the cost of installation and maintenance of capacitor banks), minimizing total harmonic distortion (THD), and minimizing node voltage deviation from 1 P.U. In this paper, the particle swarm optimization (PSO) algorithm and a new version of backward-forward sweep [15] are used for optimization and network analysis in the harmonic mode, respectively. In order to evaluate the performance of the proposed method, the problem has been solved for an 18-bus IEEE test system using the proposed approach.

2. Modeling and network analysis in the presence of nonlinear loads

Capacitor placement includes many variables such as capacitor size, capacitor cost, loss costs, voltage constraints, and harmonic distortion. Considering all of the variables in nonlinear mode will complicate capacitor placement. In this paper, in order to simplify, the network is assumed to be balanced and line admittance is neglected.

2.1. System modeling at fundamental frequency

The distribution network is constituted of residential and commercial loads including fluorescent lamps and electrical and electromagnetic gadgets. Consequently, some portions of loads are constituted of nonlinear loads.

Loads and capacitors are considered as a constant power model and constant impedance model, respectively, at the power system fundamental frequency (50 Hz). Bus currents are presented by [26,27]:

$$I_{lj}^{*} = (p_j + i \times q_j)/v_j, \tag{1}$$

$$I_{cj}^{*} = ((i \times q_{cj}) \times (v_j/v_{base})^2)/_{v_j}, \tag{2}$$

$$I_j = I_{lj} - I_{cj}, \tag{3}$$

$$p_j = p_{1j} + p_{nj}, \tag{4}$$

where I_{lj} and I_{cj} are the absorbed load current and injected capacitor current connected to the j*th* bus, and P_{lj} and P_{nj} are the corresponding power of linear and nonlinear portions of loads connected to the j*th* bus, respectively. Load flow is one of the most important tools needed for the design and operation of the distribution system. Unique topological features of distribution networks, including a wide range of reactance and resistance and a high number of branches and nodes, cause the traditional load flow methods used in transmission systems such as the Gauss–Seidel and Newton–Raphson techniques to fail in analysis of distribution systems [28]. A method commonly used to analyze and obtain the parameters of the distribution network is known as backward-forward sweep [29].

2.2. System modeling at harmonic frequencies

At higher frequencies, as shown in Figure 1, all components of the power system are modeled with a combination of harmonic current sources and passive elements [26,27]. Since the system admittances are changed at harmonic frequencies, if the skin effect is neglected, admittances of linear part of the loads, parallel capacitors, and feeder admittances at the n*th* harmonic are represented by [26]:

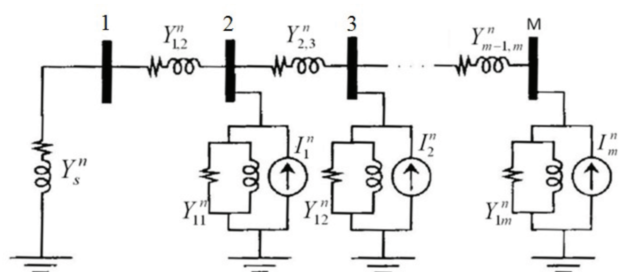

Figure 1. Equivalent circuit of the system at nth frequency.

$$Y_{1j}^{n} = \frac{p_{1j}}{\left|v_j^1\right|^2} - i \times \frac{q_{1j}}{n \times \left|v_j^1\right|^2}, \tag{5}$$

$$Y_{cj}^{n} = n \times Y_{cj}^{1}, \tag{6}$$

$$Y_{j,j+1}^{n} = \frac{1}{R_{j,j+1} + i \times n \times X_{j,j+1}}. \tag{7}$$

The linear loads are composed of a resistance in parallel with a reactance [27]. The nonlinear loads are treated as harmonic current sources, so the injection harmonic current sources introduced by nonlinear loads at bus i are introduced as follows [26]:

$$I_j^1 = \left[\frac{p_{nj} + i \times q_{nj}}{v_j^1} \right]^*, \tag{8}$$

$$I_j^n = c(n) \times I_j^1. \tag{9}$$

In this study, C(n) is obtained by field test and Fourier analysis for all the customers along the distribution feeder [26]. Despite the forward-backward sweep being a common method for the analysis of distribution networks, since the harmonic currents absorbed by the capacitors are not distinct, this method could not be used directly for network analysis in harmonic situations. If the currents absorbed by the capacitors are calculated, forward-backward sweep can be used to calculate the relationships between the harmonic current (nonlinear load), branch current, and bus voltage in each harmonic frequency. In [15] network parameters are specifically given and they are added to the forward-backward sweep in order to calculate them in harmonic conditions.

3. Mathematical modeling of distributed generation system for harmonic load Flow

In this paper, wind power with a double-fed induction generator is used as the distributed generation unit. The double-fed induction generator model is shown in Figure 2. If a wind turbine is used as the source of distributed generation and a component of the distribution system, it is necessary that impacts and changes of this production unit be checked in network connectivity and the network voltage level. In addition, the distribution networks are usually radial and power flows in one direction. However, with the addition of distributed generation resources, radial characteristics of the distribution network change. Therefore, an appropriate model should be used for investigating these units.

Wind turbines produce oscillation continuous power, which bulks up their power dependence on wind input. Wind speed oscillatory nature and power fluctuations cause the importance of power quality issues in these generators to increase. Therefore, it is necessary that an appropriate wind speed model on all surfaces of the rotor be achieved for more accurate simulation. PSAT software is used for this purpose, which is a MATLAB software toolbox. There are 2 models for wind speed simulation in the mentioned software. In this paper, the Weibull model is used. Figure 3 shows a time series of wind generated by this model.

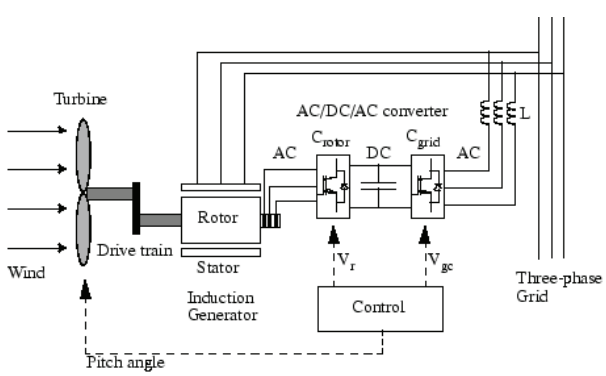

Figure 2. Double-fed induction generator model.

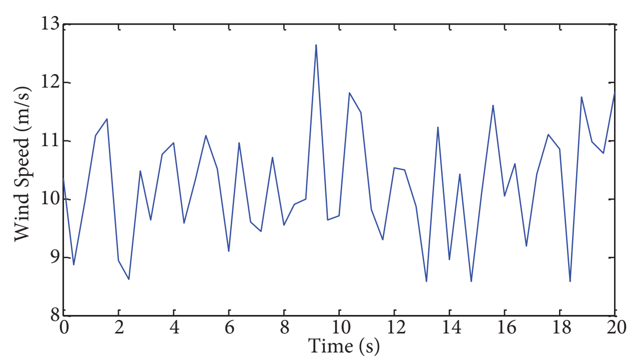

Figure 3. A sample of wind generated by the Weibull model.

As already noted, nonlinear loads are modeled by current source with a distinct amplitude at each harmonic frequency. This rule is well established for currents controlled by pulse width modulation (PWM) converters [30]. Since this kind of generator also uses PWM converters, the current harmonic spectrum of the wind turbine generator is obtained at the generator bus by the Simulink toolbox of MATLAB software. This spectrum is added to the load flow as a current source at each harmonic frequency. Figure 4 illustrates this harmonic current spectrum.

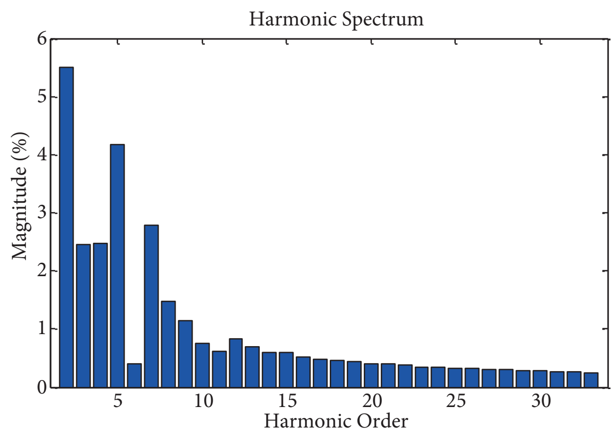

Figure 4. Wind power output harmonic current spectrum.

To study the effects of wind power units in the network, load flow should be used. In large and manageable distributed generation such as the double-fed induction generator, active power output and generator bus voltage amplitude are determined and fixed. The distributed generation bus in this type of plant can be introduced as a controlled bus model (PV) in the load flow [31]. In this paper, a suitable model is used to add distributed generation units into the distribution network load flow. Specified parameters of this distributed generation model are output real power and bus voltage magnitude. In this model, to calculate the equivalent current injection to the load flow method, a two-loop algorithm is needed. The first loop computes the reactive power of distributed generation that is needed for maintaining the bus voltage amplitude at a determined value. After calculation of reactive power output, the second loop determines the equivalent current injection and adds it into power flow analysis. Details of this method are described in [31,32].

4. Problem formulation

Different methods have been proposed for solving optimization problems with multiple objectives. One of them is defining each of these goals in the form of fuzzy membership functions and integrating them into a fuzzy satisfaction objective function, F, through appropriate weighting factors as given below [33]:

$$\max F = w_1 \mu_S + w_2 \mu_V + w_3 \mu_T, \tag{10}$$

where μ_S is the rate of the net saving membership function of capacitor installation, μ_V is the rate of the bus voltage deviation membership function, μ_T is the rate of the harmonic failure reduction membership function, and $W_{1,2,3}$ are the weighting coefficients according to the project goals and their sum is equal to 1. Designer opinions for determining capacitors' size and position could be applied by determining appropriate weighting coefficients and the shape of membership functions associated with each of the project objectives. The fuzzy membership function expresses the degree of satisfaction of objectives and entertains varying membership function values from zero to unity. The membership functions used in this paper follow below.

4.1. Membership function for net savings

Profit obtained from capacitor placement is determined by the following relation:

$$S = K_e \times T \times (PL - PL^c) + K_a(PL - PL^c) - \sum_{i=1}^{nc} K_c Q_{ci}, \tag{11}$$

where K_e is the cost per megawatt-hour (e.g., K_e = 50 US $/MWh [34]), K_a is savings per megawatt for reduction in losses (e.g., K_a = 120,000 US $/MW [34]), PL is power losses at peak load before installation of capacitors, PL^c is power losses at peak load after capacitor installation, Q_{ci} is capacitor capacity at the ith node, and nc is number of locations where the capacitors are installed. Eq. (11) must be greater than zero to make a profit from the capacitor installation process. Therefore, if S becomes larger, more profit will be obtained and desirability would be more. The economic benefit membership function is shown in Figure 5A. S_{max} can have a single-objective function value or any other amount considered by the designer.

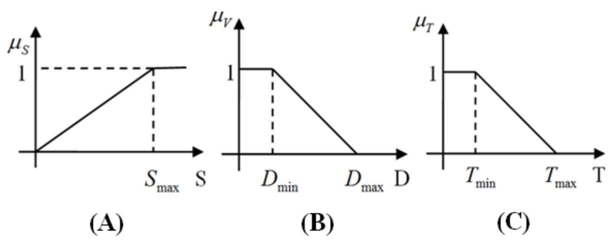

Figure 5. Membership function for (A) net savings, (B) voltage deviation, and (C) harmonic distortion.

4.2. Membership function for maximum voltage deviation

The basic purpose of this membership function is that the deviation of node voltage should be less. Bus voltage deviation is obtained from the following relation:

$$D = Max\,|V_S - V_i| \quad for\ i = 2, 3, ..., nb\ , \tag{12}$$

where V_i is the ith bus voltage obtained from Eq. (13), V_s is substation bus voltage magnitude, and n_b is the number of system buses. The membership function of declining the buses' voltage deviation is shown in Figure 5B.

$$|V_i| = \sqrt{\sum_{h=1}^{n} \left|V_i^{(h)}\right|^2} \tag{13}$$

Power quality standards usually determine a maximum permissible value (e.g., 1.05 P.U.) and minimum permissible value (e.g., 0.95 P.U.) for bus voltage. D_{max} and D_{min} are chosen considering the mentioned constraints by the designer.

4.3. Membership function for harmonic distortion

The presence of harmonics in the power system network, in addition to increasing losses, will cause failures and increase temperature in sensitive loads. One of the necessary steps to improve power quality is thus the minimization of power system harmonics. Network harmonics are calculated by the THD index, which is expressed by:

$$THD_i = \frac{\sqrt{\sum_{h=2}^{n} \left|V_i^{(h)}\right|^2}}{\left|V_i^{(1)}\right|}. \tag{14}$$

The THD membership function is shown in Figure 5C. According to IEEE-519, the acceptable level of THD is 5%. Thus, in this paper, T_{min} and T_{max} are considered as 0 and 0.05, respectively.

4.4. Constraints

Various constraints may be considered for this issue but the most common one is the limitation of bus voltage. The limitation states that the voltage of all buses should not exceed the minimum and maximum distinct values and always should be within the permitted range.

$$V_{\min} \leq V_i \leq V_{\max} \tag{15}$$

Furthermore, regarding economic and technical considerations, capacitor placement in distribution networks is usually done so that the total capacitance of the grid does not exceed a specified limit (Q_{max}). There is not actually a possibility of installation of capacitors in some buses.

$$\sum_{j=1}^{nc} Q_c^j \leq Q_{\max} \tag{16}$$

5. Particle swarm optimization

5.1. Algorithm introduction

PSO is a population-based optimization technique first proposed by Kennedy and Eberhart [35]. The main idea of the PSO algorithm is modeling and simulation of movement and group behavior of birds searching for food. In PSO, each particle is a possible answer to the multidimensional space of problem. The most important features of this algorithm are that it is easy to implement and does not require information derived by equations. The algorithm can be used in a wide range of optimization problems.

In the classical PSO algorithm, each particle has two main parts, including the current position of the particle (X_i) and the current particle velocity (V_i), which are expressed in N-dimensional space of the optimization problem as follows:

$$\begin{array}{l} X_i\left(t\right) = \left(x_i^1\left(t\right), x_i^2\left(t\right), \ldots, x_i^n\left(t\right)\right) \\ V_i\left(t\right) = \left(v_i^1\left(t\right), v_i^2\left(t\right), \ldots, v_i^n\left(t\right)\right) \end{array}. \tag{17}$$

The next position of each particle in the search space is determined by the current position and the next velocity. The next velocity of each particle is determined by four main factors, namely the current velocity of the particle, the particle's current position, the best current position of the particle ($P_i^b(t)$) that has been experienced by it so far and stored in memory, and the best position among the particles of the group ($P^g(t)$), which is known as group experience. According to the above definition, the next velocity of each particle is expressed as follows:

$$\begin{array}{c} v_{i,j}\left(t+1\right) = wv_{i,j}\left(t\right) + c_1 rand\left(\cdot\right)\left[P_{i,j}^b\left(t\right) - x_{i,j}\left(t\right)\right] \\ +c_2 Rand\left(\cdot\right)\left[P_j^g\left(t\right) - x_{i,j}\left(t\right)\right] \end{array}, \tag{18}$$

where w is the particle inertia coefficient for moving with the previous velocity, and C_1 and C_2 are individual and group learning coefficients of particles. *Rand(0)* and *Rand(1)* are random numbers in the range of [0, 1], maintaining the probabilistic feature of the algorithm. $P_{i,j}^{b}$ is the j*th* dimension of the best position of the i*th* particle and P_{j}^{g} is the j*th* dimension of the best position among all particles. These parameters are achieved by evaluating each particle through the objective function. The inertia coefficient, w, is very effective for the algorithm convergence and determining an optimal solution, and it is expressed as follows:

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{Itr_{\max}} Itr, \tag{19}$$

where w_{min} and w_{max} are the minimum and maximum of the inertia coefficient, respectively. Itr_{max} is the maximum iteration number of the algorithm processes and *Itr* is the current iteration number of the algorithm. By determining the next velocity of each particle, the next position of them is derived by:

$$x_{i,j}\left(t+1\right) = x_{i,j}\left(t\right) + v_{i,j}\left(t+1\right). \tag{20}$$

5.2. Application process of PSO

The problem-solving process using the PSO method is briefly as follows.

First step: Initialization

At this stage, an initial population is produced by a randomly generated position and velocity of particles in the permitted range.

Second step: Objective function evaluation

In this step, constraints for each particle are investigated first. Thus, the amount of penalty is assigned to each of the particles proportional to the degree of violation from constraints. The amount of objective function is then calculated for each particle by Eq. (10). By adding the penalty factor, the fitness of each particle is calculated.

Third step: Determine the best position of the particle

In this stage, the best position of each particle ($P_i^b(t)$) is obtained from particle position compared with its previous iterations position. Furthermore, with determining the best position in the current iteration (particle that has the lowest value of the objective function) and comparing it with the previous iterations, the best particle position that has ever been produced, ($P^g\left(t\right)$), is defined.

Forth step: Updating velocity

The velocity of each particle in the current iteration is updated using Eq. (18).

Fifth step: Updating position

The new position of each particle is updated according to the updated velocities using Eq. (20).

Sixth step: Number of iterations survey

If the iteration number does not exceed the maximum permitted number of iterations, jump to the second step. Otherwise, go to the seventh step.

Seventh step: Algorithm stopping

6. Simulation results

In this paper, the 18-bus distorted IEEE distribution system has been used for numerical study. The base voltage and power of this system are 23 kV and 10 MW, respectively. A single-line diagram of the system is shown in Figure 6 and the details of loads and lines are given in [36].

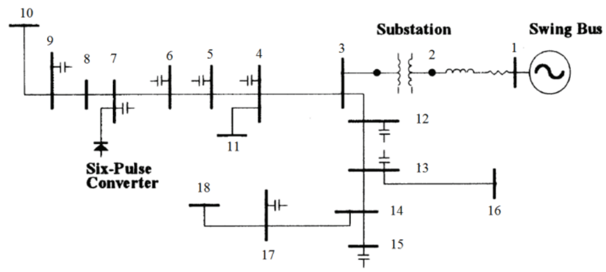

Figure 6. Single-line diagram of 18-bus distorted IEEE distribution system.

In this paper, a wind turbine with a double-fed induction generator has been added to bus number 10 in order to show the destructive effects of distributed generation on power quality and provide a way to improve them. The nominal power and voltage range of this turbine are 1 MW and 1.04 P.U., respectively. Since this kind of wind turbine can control and stabilize bus generators voltage at the adjusted level, it can be added to the harmonic load flow as a controlled bus (PV) [31]. Wind speed oscillatory nature and power fluctuations cause the importance of power quality issues in these generators to increase. First an appropriate model for wind speed is produced by the Weibull model of PSAT software. The harmonic current spectrum of the wind turbine is then calculated by the Simulink toolbox. As mentioned in Section 3, this current spectrum is added to the harmonic load flow as the current source [30]. Details of this method as well as the wind model and harmonic current spectrum were described in Section 3.

As mentioned above, the process of optimal capacitor placement is focused on as a way to improve the harmonic distortions. Since distributed generation can play a great role in weakening the system power quality, lack of attention to distributed generation can keep the goal from being met. Therefore, in this paper, to show and prove the side effects of distributed generation, two tests are pursued. In the first experiment, a unit of the proposed wind power plant is added at bus number 10 of the network with the existing capacitors before optimization. Harmonic distortions, voltage, and losses before and after the addition of wind power are investigated. Figure 7 and Table 1 represent the network parameters before and after the addition of wind turbines.

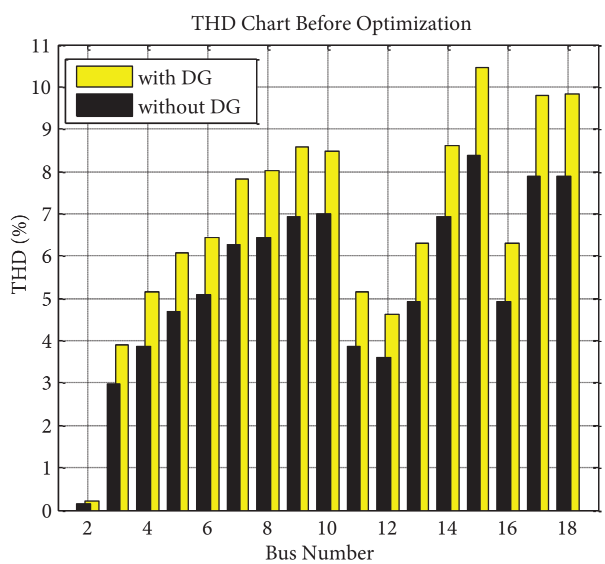

Figure 7. Comparison of THD with existing network capacitors with and without distributed generation (DG).

Table 1. Comparison of network parameters with existing capacitors with and without distributed generation (DG).

	Losses (kW)	Voltage min (P.U.)	Voltage max (P.U.)	THD max (%)	Benefit
Without DG	282.55	1.029	1.055	8.48	6.2628×10^4
With DG	255.7	1.0437	1.0582	10.47	7.7608×10^4

Figure 7 shows that the presence of the wind power plant worsens the power quality at all buses. The maximum value of THD increases 2.01% and reaches 10.47%. According to Table 1, the maximum value of the voltage has more difference from the permitted value by the IEEE-519 standard in the presence of the wind power plant.

In the second experiment, to investigate the effect of distributed generation's presence on optimal location and size of capacitors, the results of [18] are analyzed. The optimal capacitor placement was investigated in [18] without distributed generation. In this paper, the optimal capacitors reported by [18] are connected to the network. A proposed wind power is then added to bus number 10. After that, network parameters are analyzed in the presence of distributed generation. The location and size of capacitors reported by [18] and the results of this study are shown in Figures 8 and 9 and Table 2.

Table 2. Network parameter comparison with obtained optimal capacitors without DG ([18]) and with DG.

	Losses (kW)	Voltage min (P.U.)	Voltage max (P.U.)	THD max (%)	Capacitor installation benefit
Without DG	249	1.006	1.051	4.706	8.1224×10^4
With DG	212.3	1.003	1.06	5.866	10.255×10^4

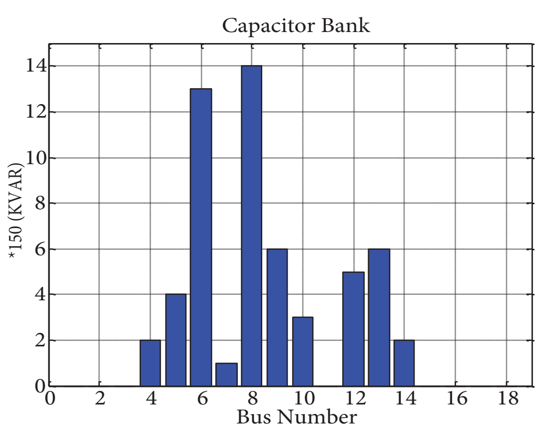

Figure 8. Size and location of capacitors obtained by [18].

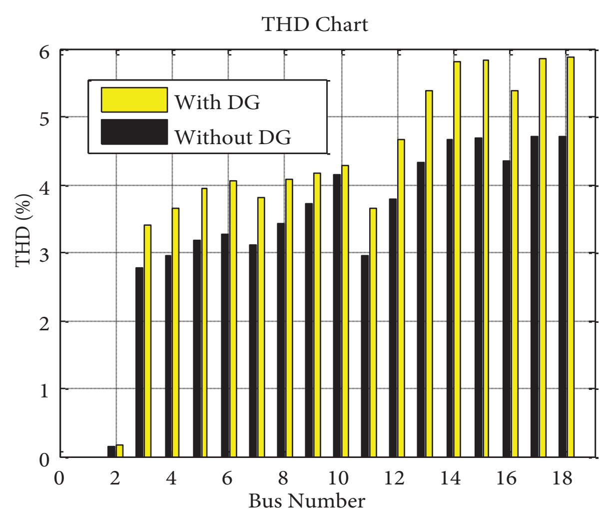

Figure 9. Bus voltage THD comparison with obtained optimal capacitors without DG ([18]) and with DG.

Figure 9 shows that the algorithm proposed in [18] without distributed generation reduces harmonic distortions of all buses and attains the permitted values. However, if the mentioned wind power is added, some buses' harmonic distortions will be still more than the permitted value. In this situation, the maximum value of THD grows 1.16%. Table 2 also shows that with the addition of a wind power plant the maximum voltage is far increased and the difference from permitted values is exceeded.

As was shown, distributed generation being added to the network (with or without optimal capacitors) weakens the system power quality. It causes the maximum capacity of distributed generation units to not be used in order to improve power quality. One of the ways to liberalize distributed generation capacity is replacement and finding the optimal capacity and location of capacitors in the presence of distributed generation sources. Therefore, in the next section, optimal capacitor placement in the presence of distributed generation is pursued by the proposed algorithm and the conclusion is shown in Figure 10.

Figure 11 and Table 3 show bus voltage THD and the network parameters respectively in the presence of distribute d generation with the algorithm proposed in this paper.

Table 3. Network parameters in optimal capacitor placement with proposed algorithm in the presence of DG.

Losses (kW)	Voltage min (P.U.)	Voltage max (P.U.)	THD max (%)	Capacitor installation benefit
227.51	0.9976	1.05	3.656	9.3136×10^4

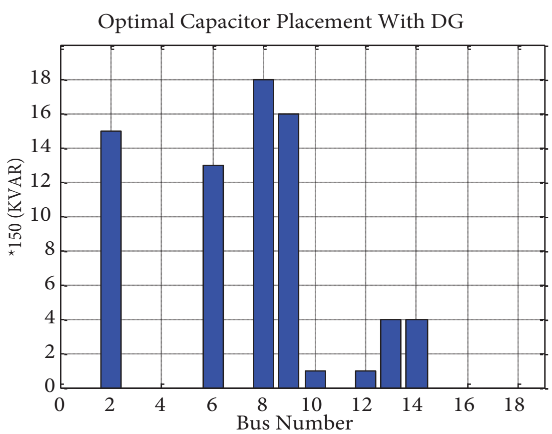

Figure 10. Optimal location and size of capacitor banks in the presence of DG by proposed model.

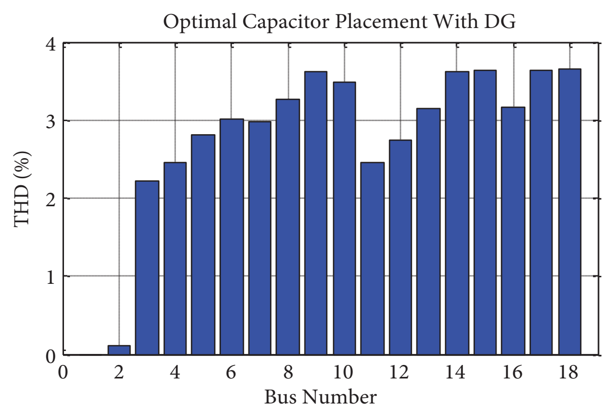

Figure 11. Bus voltage THD in optimal capacitor placement with proposed algorithm in the presence of DG.

According to Table 3 and Figure 11, this method decreases THD values significantly in all buses and limits them to the permitted level. The maximum THD reaches 3.656%, which declines 6.814% and 2.21% compared with the first and second experiments, respectively. Furthermore, Table 3 shows that the proposed method limits all buses' voltages to the desired range, while unacceptable bus voltage deviation could be observed in previous experiments. The maximum bus voltage is 1.05 P.U. in the proposed method, whereas this parameter is 1.058 and 1.06 P.U. for first and second experiments, respectively. It is significant that the proposed method is an appropriate and flexible algorithm for compatibility with network needs and designer opinions. For example, if loss reduction and annual profit are more significant, the designer can boost weight coefficient W_1. The proposed method is thus an appropriate software package for optimal capacitor placement in the presence of nonlinear loads and wind power in order to achieve loss reduction and power quality enhancement. With the help of this method, maximum capacity of distributed generation can be used without any power quality restrictions.

7. Conclusion

The presence of distributed generation sources in a power system, despite the widespread advantages, has some problems, such as increasing harmonic distortion and sometimes increasing the voltage deviation from allowed values. On the other hand, capacitor banks play an important role in reducing network losses and improve harmonic distortion. However, choosing the location and the size of the capacitor bank incorrectly could not only could not boost power quality but could also destroy it. Due to inattention to nonlinear loads as an extensive part of consumer loads and growing distributed generation resources, the capacitor placement process not only moves away from optimal location and size but can also cause more problems in system power quality. In this paper, side effects of distributed generation on system power quality were demonstrated and proved. Capacitor banks were introduced as an appropriate method for improving them and releasing the distributed generation capacity. In this regard, optimal capacitor placement in the presence of distributed generation and nonlinear loads was formulized as a fuzzy multiobjective method so that constraints and power quality parameters were considered as a part of the optimization goals. PSO and a special version of the forward-backward sweep were used to solve the proposed model. The results of experiments accomplished on an 18-bus IEEE distributed network illustrated the importance of distributed generation resources and their impact on the capacitor placement, and also the impact of capacitor banks on network power quality. Simulation results showed that when adding distributed generation into a network, the capacitor placement should be done again regarding distributed generation in order to release distributed generation capacity and boost power quality. Experimental results indicated that the proposed method is an efficient method for locating capacitor banks in order to reduce losses and improve network power quality parameters. The proposed method is an appropriate software package for capacitor placement in the presence of wind power and nonlinear loads, since it is a flexible method regarding designer opinions and network concerns.

References

[1] Bollen MJ, Yu-Hua I. Signal Processing of Power Quality Disturbances. Hoboken, NJ, USA: John Wiley & Sons, 2006.

[2] Carlisle JC, El-Keib AA, Boyd D, Nolan K. A review of capacitor placement techniques on distribution feeders. In: Proceedings of the 29th Southeastern Symposium on System Theory; 1997; Washington DC, USA. New York, NY, USA: IEEE. pp. 359–365.

[3] Ng HN, Chikhani AY. Classification of capacitor allocation techniques. IEEE T Power Deliver 2000; 15: 387–392.

[4] Duran H. Optimum number, location and size of shunt capacitors in radial distribution feeders: a dynamic programming approach. IEEE T Power Ap Syst 1968; 87: 1769–1774.

[5] Segura S, Romero R, Rider MJ. Efficient heuristic algorithm used for optimal capacitor placement in distribution system. Int J Elec Power 2010; 32: 71–78.

[6] Da Silva IC. A heuristic constructive algorithm for capacitor placement on distribution systems. IEEE T Power Syst 2008; 23: 1619–1626.

[7] Sundhararajan S, Pahwa A. Optimal selection of capacitors for radial distribution systems using a genetic algorithm. IEEE T Power Syst 1994; 9: 1499–1507.

[8] Delfanti M, Granelli GP, Marannino P, Montagna M. Optimal capacitor placement using deterministic and genetic algorithms. IEEE T Power Syst 2000; 15: 1041–1046.

[9] Masoum MAS, Ladjevardi M, Jafarian A, Fuchs EF. Optimal placement, replacement and sizing of capacitor banks in distorted distribution networks by genetic algorithms. IEEE T Power Deliver 2004; 19: 1794–1801.

[10] Ellithy K, Hiniai AL, Moosa A. Optimal shunt capacitor allocation in distribution networks using genetic algorithm - practical case study. INT J Elec Power 2008; 3: 13–45.

[11] Chiang HD, Wang JC, Cockings O, Shin HD. Optimal capacitor placements in distribution systems, Part I: A new formulation and the overall problem. IEEE T Power Deliver 1990; 5: 634–642.

[12] Chiang HD, Wang JC, Shin HD. Optimal capacitor placement in distribution systems, Part II: Solution algorithms and numerical results. IEEE T Power Deliver 1990; 5: 643–649.

[13] Yang HT, Huang YC, Huang CL. Solution to capacitor placement in a radial distribution system using tabu search method. In: International Conference on Energy Management and Power Delivery; 21–23 November 1995; Singapore. New York, NY, USA: IEEE. pp. 388–393.

[14] Chang CS, Lern LP. Application of tabu search strategy in solving non differentiable savings function for the calculation of optimum savings due to shunt capacitor installation in a radial distribution system. IEEE Power Eng Soc 2000; 4: 2323–2328.

[15] Teng JH, Chang CY. Backward/forward sweep-based harmonic analysis method for distribution systems. IEEE T Power Deliver 2007; 22: 1665–1672.

[16] Masoum MAS, Jafarian A, Ladjevardi M, Fuchs EF, Grady WM. Fuzzy approach for optimal placement and sizing of capacitor banks in the presence of harmonics. IEEE T Power Deliver 2004; 19: 822–829.

[17] Abdelgany IT. Optimal sizing of capacitor banks and distributed generation in distorted distribution networks by genetic algorithms. In: 20th International Conference and Exhibition on Electricity Distribution; 8–11 June 2009; Prague, Czech Republic. New York, NY, USA: IEEE. pp. 1–4.

[18] Taher SA, Karimian A, Hasani M. A new method for optimal location and sizing of capacitors in distorted distribution networks using PSO algorithm. Simul Model Pract Th 2011; 19: 662–672.

[19] Taher SA, Hasani M, Karimian A. A novel method for optimal capacitor placement and sizing in distribution system with nonlinear loads and DG using GA. Commun Nonlinear Sci 2011; 16: 851–862.

[20] Elmitwally A. Optimal sizing and location of capacitor banks in distributed distortion networks with distributed wind generation. In: 21st International Conference on Electricity Distribution; 6–9 June 2011; Frankfurt, Germany.

[21] Heydari M, Hosseini AM, Gholamian SA. Optimal placement and sizing of capacitor and distributed generation with harmonic resonance consideration using discrete particle swarm optimization. International Journal of Intelligent Systems and Applications 2013; 7: 42–49.

[22] Wang M. A novel method for distributed generation and capacitor optimal placement considering voltage profile. In: IEEE Power and Energy Society General Meeting; 24–29 July 201; San Diego, CA, USA. New York, NY, USA: IEEE. pp. 1–6.

[23] Kalantari M. Placement of distributed generation unit and capacitor allocation in distribution systems using genetic algorithm. In: 10th International Conference on Environment and Electrical Engineering; 8–11 May 2011; Rome, Italy. New York, NY, USA: IEEE. pp. 1–5.

[24] Sadighmanesh A, Zare K, Sabahi M. Generation unit and capacitor placement for multi objective optimization. International Journal of Electrical and Computer Engineering 2012; 2: 614–620.

[25] Ardakani MHM, Mahmudabadi MZ, Zabihi MH, Khodadadi A. Distributed generation and capacitor banks placement in order to achieve the optimal real power losses using GA. International Journal of Computer Science and Technology 2011; 2: 400–404.

[26] Chung TS, Leung HC. A genetic algorithm approach in optimal capacitor selection with harmonic distortion considerations. Int J Elec Power 1991; 21: 561–569.

[27] Baghaouz Y. Effects of nonlinear loads on optimal capacitor placement in radial feeders. IEEE T Power Deliver 1991; 6: 245–251.

[28] Tripathy SC, Prasad GD, Malik OP, Hope GS. Load flow solutions for ILL-conditioned power system by a Newton-link method. IEEE T Power Ap Syst 1982; 101: 3648–3657.

[29] Shirmohamad D, Hong HW, Semlyen A. A compensation-based power flow method for weakly meshed distribution and transmission networks. IEEE T Power Syst 1988; 3: 753–762.

[30] Papathanassious SA, Papadopoulos MP. Harmonic analysis in a power system with wind generation. IEEE T Power Deliver 2006; 21: 2006–2016.

[31] Teng JH. Modelling distributed generations in three-phase distribution load flow. IET Gener Transm Dis 2007; 2: 330–340.

[32] Teng JH. A direct approach for distribution system load flow solutions. IEEE T Power Deliver 2003; 18: 882–887.

[33] Dos D. Optimal placement of capacitors in radial distribution system using a fuzzy-GA method. Int J Elec Power 2008; 30: 361–367.

[34] Ladjavardi M, Masoum MAS. Genetically optimized fuzzy placement and sizing of capacitor banks in distorted distribution networks. IEEE T Power Deliver 2008; 23: 449–456.

[35] Kennedy J, Eberhart R. Particle swarm optimization. In: Proceedings of IEEE International Conference on Neural Networks; 27–30 November 1995; Perth, Australia. New York, NY, USA: IEEE. pp. 1942–1948.

[36] Grady WM, Samotyj MJ, Noyola AH. The application of network objective functions for actively minimizing the impact of voltage harmonics in power systems. IEEE T Power Deliver 1992; 7: 1379–1386.