A NEW APPROACH TO OPTIMIZE THE APFS PLACEMENT BASED ON INSTANTANEOUS REACTIVE POWER THEORY BY GENETIC ALGORITHM

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In electrical distribution systems, a great amount of power are wasting across the lines, also nowadays power factors, voltage profiles and total harmonic distortions (THDs) of most loads are not as would be desired. So these important parameters of a system play highly important role in wasting money and energy, and besides both consumers and sources are suffering from a high rate of distortions and even instabilities. Active power filters (APFs) are innovative ideas for solving of this adversity which have recently used instantaneous reactive power theory. In this paper, a novel method is proposed to optimize the allocation of APFs. The introduced method is based on the instantaneous reactive power theory in vectorial representation. By use of this representation, it is possible to asses different compensation strategies. Also, APFs proper placement in the system plays a crucial role in either reducing the losses costs and power quality improvement. To optimize the APFs placement, a new objective function has been defined on the basis of five terms: total losses, power factor, voltage profile, THD and cost. Genetic algorithm has been used to solve the optimization problem. The results of applying this method to a distribution network illustrate the method advantages.

K e y w o r d s: active power filters (APFs), optimized placement, power loss, total harmonic distortion (THD), genetic algorithm (GA), instantaneous reactive power theory

1 INTRODUCTION

The extensive use of nonlinear devices, power system electrical equipments and home appliances and wide spread of nonlinear loads such as computers, lighting, rectifier equipments in telecommunication networks, adjustable speed drivers (ASD), static power supplies (SPS) and uninterrupted power supplies (UPS) cause a deterioration of power quality in power systems [1, 2]. They draw non-sinusoidal unbalanced current from ac supplies resulting in reactive power requirement, harmonic injection, excessive neutral currents and unbalanced loading [2]. The large reactive power decreases lines transmission capabilities, and increases power loss in distribution system. Studies indicate that as much as 13% of total power generated is wasted in the form of losses at distribution levels [3]. Moreover, harmonics can harm the safety and reliability of power system and disturb the accurate operation of the consumer products, equipment overheating, capacitor blowing, motor vibration, excessive neutral currents and low power factors. Harmonics not only consume reactive power reserved, but also produce extra losses on power systems [2, 4, 5].

To solve these problems such as: reactive power compensation, unbalanced load correction and harmonic mitigation, some methods have been considered: passive filters [6, 7], shunt capacitors [8–10], narrow band filters [11] synchronous machines, static var compensators (SVC) [12], reconfiguration [13–16], resizing and using distributed generation (DG) [17]. Each of the suggested methods has some weakness. The passive LC filters used to be applied; however, large size, resonance problems,

overloads and inability of adapting to network characteristic variation or variable loads made them ineffective [1, 18]. Shunt capacitors can cause harmonic and resonance. Also, they have inrush problems during connection and disconnection [19]. Synchronous machines are massive and have an unfavorable dynamic behavior. Also, SVCs are harmonic polluters [12]. Therefore, active power filters (APFs) recently draw researchers attention and some progress have been achieved in this field.

The concept of harmonic elimination, reactive power compensation and unbalanced load correction by APFs come back to almost two decades ago. Up to now, their formulations and applications have attracted great attention [20]. Using APFs not only compensate reactive power required by loads, but make currents sinusoidal and in phase with supply voltages. Their different strategies can provide system by different types of compensation. Furthermore, they can accurately calculate and find needed compensation current for each phase, so its application in power systems is much better than other mentioned methods.

Akagi *et al* [21] introduced instantaneous reactive power theory or *p–q* theory at the beginning of eighties, since then most of the APFs have used controlled compensation currents obtained by this theory. The *p–q* theory has been achieved by transferring voltages and currents from 3-phase basic to $0_{\alpha\beta}$ origin. The former original methods applied Clark transformation matrices, and they used difficult mapping matrices to present their objective in the form of matrices; However, the vectorial approach avoids difficulty of mapping matrices calcula-

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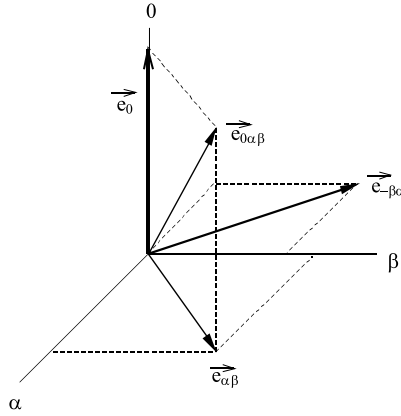
Fig. 1. Voltage vectors in $0\alpha\beta$ space [22]

tions, so can easily provide compensation currents [22]. Furthermore, prime theory could just compensate when objective was to have a constant power. So, it provided pulsating value of load active power in order to have constant power. However, in the case that source voltages are non-sinusoidal and/or unbalanced the former method cannot solve the problems. Therefore, it needs reformulation proposed in [22]. This new method has been named vectorial representation of p–q theory which has made the calculations easier and extended the compensation objectives of APFs.

In this paper, by use of the instantaneous reactive power theory based on vectorial representation, the control of compensators in three strategies: constant power, unity power factor and unbalanced and/or non-sinusoidal current compensation is explained. The placement of compensators is one of the most important parameters of system design. Therefore, a novel objective function has been introduced. The proposed objective function consists of five terms: total loss, power factor (PF), voltage profile (VP), total harmonic distortion (THD) and cost. To solve the optimization problem, the genetic algorithm is used. The method of finding the optimized placement of APFs has been applied to a typical 5-bus distribution system simulated in MATLAB simulink toolbox. The obtained results demonstrate that the distribution system with optimum solution is in appropriate condition for system power losses, PF, VP and THD.

2 INSTANTANEOUS REACTIVE POWER THEORY

Almost two decades ago, the instantaneous reactive power theory or p–q theory was proposed by Akagi *et al* [21]. Since then, many approaches have been published to improve this theory in theoretical and practical aspects to work under different distortion conditions in order to calculate compensation controlled current using in active power filters. These approaches include cross product formulation [23], the p–q–r formulation [24], the d–q formulation [25], and the vectorial formulation [22]. All of them consider two parts of power – instantaneous active power

$p(t)$ and reactive power $q(t)$ – as main parameters of their formulations in system analyses for transferring power between source and loads. Actually, these power parts are obtained by different components of current crossing the lines. Instantaneous active power $p(t)$ is defined as the voltage and current vectors dot product, while instantaneous reactive power $q(t)$ is the cross product of voltage and current vectors [4, 26]. They together constitute total power transferring between source and loads.

The generalized instantaneous reactive power theory applies Clark transformation [27] to map three-phase instantaneous voltage and current in the *abc* phases into $0_{\alpha\beta}$ reference. The voltages and currents on $0_{\alpha\beta}$ origin are obtained by

$$\begin{bmatrix} e_0 \\ e_\alpha \\ e_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad (1)$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (2)$$

Now, it is necessary to define different terms of power in $0_{\alpha\beta}$ origin and apply the calculations related to each compensation strategies on them. There are three important terms of power: zero sequence instantaneous real power p_0, the $\alpha\beta$ instantaneous real power $p_{\alpha\beta}$, and instantaneous imaginary power $q_{\alpha\beta}$ which are defined as

$$\begin{bmatrix} p_0 \\ p_{\alpha\beta} \\ q_{\alpha\beta} \end{bmatrix} = \begin{bmatrix} e_0 & 0 & 0 \\ 0 & e_\alpha & e_\beta \\ 0 & -e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \qquad (3)$$

The original instantaneous reactive power theory is developed from mapping matrices introduced in (1), (2), (3). However, vectorial approach defines some more concepts of voltage and current vectors in $0\alpha\beta$ reference to prevent using matricidal concepts, so make easier the currents calculation and application of this theory to APFs. According to vectorial approach, three voltage vectors, e_0, $e_{\alpha\beta}$ and $e_{-\beta\alpha}$ are defined as shown in Fig. 1.

$$\boldsymbol{e}_{\alpha\beta} = \begin{bmatrix} 0 \\ e_\alpha \\ e_\beta \end{bmatrix}, \; \boldsymbol{e}_{-\beta\alpha} = \begin{bmatrix} 0 \\ e_{-\beta} \\ e_\alpha \end{bmatrix}, \; \boldsymbol{e}_0 = \begin{bmatrix} e_0 \\ 0 \\ 0 \end{bmatrix}, \; \boldsymbol{i} = \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix}, \qquad (4)$$

where $\boldsymbol{e}_{-\beta}$ and $\boldsymbol{e}_0$ are the orthogonal and zero sequence voltage vectors respectively and the following three facts can be verified

$$\boldsymbol{e}_{0\alpha\beta} = \boldsymbol{e}_0 + \boldsymbol{e}_{\alpha\beta}, \qquad (5)$$

$$\boldsymbol{e}_{-\beta\alpha} \cdot \boldsymbol{e}_{0\alpha\beta} = 0, \qquad (6)$$

$$\boldsymbol{e}_0 \cdot \boldsymbol{e}_{\alpha\beta} = 0. \qquad (7)$$
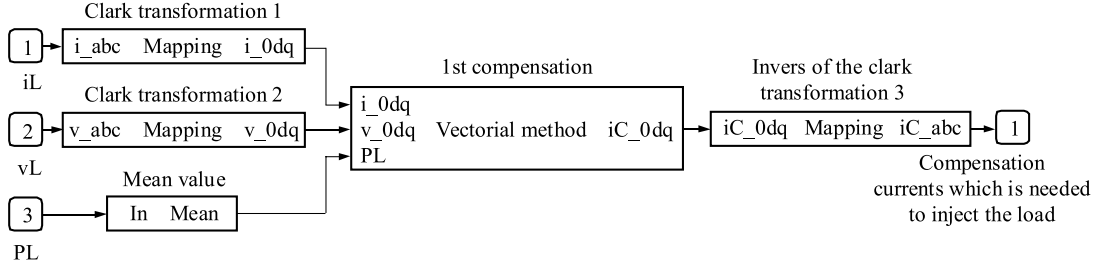
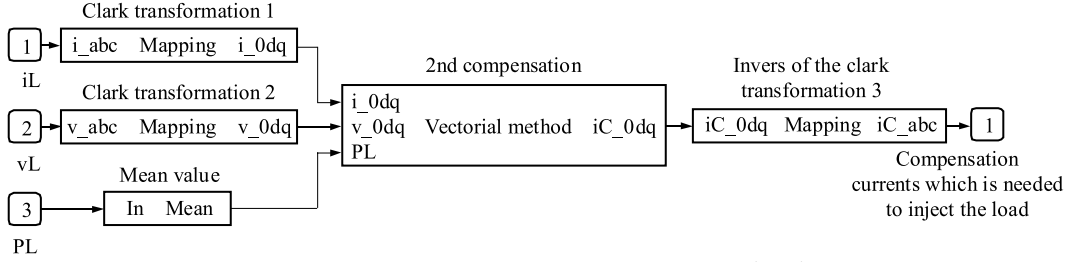**Fig. 2.** First compensation strategy blocks in MATLAB

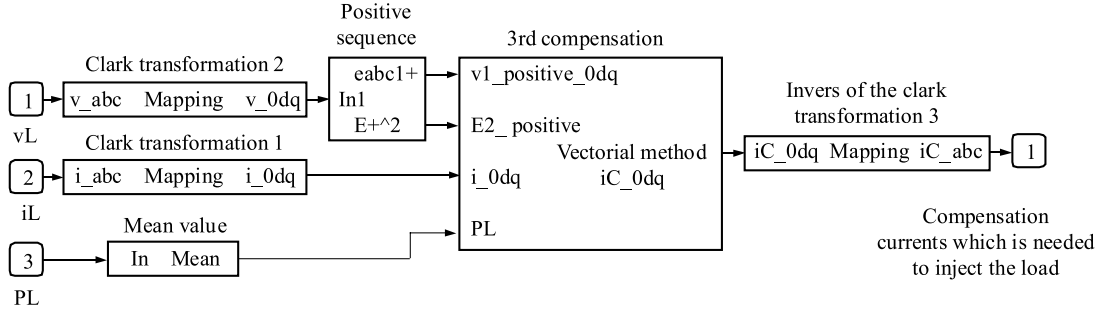**Fig. 3.** Second compensation strategy blocks in MATLAB

Fig. 4. Third compensation strategy blocks in MATLAB

The current vector may be composed as the sum of its projection over different voltage terms e_0, $e_{\alpha\beta}$ and $e_{-\beta\alpha}$ which is [22]

$$\boldsymbol{i} = \frac{p_{\alpha\beta}(t)}{\boldsymbol{e}_{\alpha\beta} \cdot \boldsymbol{e}_{\alpha\beta}} \boldsymbol{e}_{\alpha\beta} + \frac{q_{\alpha\beta}(t)}{\boldsymbol{e}_{-\beta\alpha} \cdot \boldsymbol{e}_{-\beta\alpha}} \boldsymbol{e}_{-\beta\alpha} + \frac{p_0(t)}{\boldsymbol{e}_0 \cdot \boldsymbol{e}_0} \boldsymbol{e}_0 \,. \quad (8)$$

3 THREE COMPENSATION STRATEGIES

In this paper, three different control strategies for compensators in p–q theory are explained.

- First strategy — constant power compensation,
- Second strategy — unity power factor,
- Third strategy — non-sinusoidal and/or unbalanced currents compensation.

In the first compensation strategy, the main purpose is to make source power a constant value. So, compensator should provide pulsating value of load power. Therefore, source current vector $\boldsymbol{i}_S(t)$ should be in phase with $\boldsymbol{i}_{\alpha\beta}$ to have constant active power from the source, so

$$\boldsymbol{i}_S(t) = K\boldsymbol{e}_{\alpha\beta} \,, \quad (9)$$

K is a constant value. The aim of this compensation is reaching to a simple relation between the load active power mean value P_L and source power

$$p_S(t) = P_L \,. \quad (10)$$

Also, the active power receiving from the source is calculated by dot product of source voltage and current vectors

$$p_S(t) = \boldsymbol{e}_{0\alpha\beta}(t) \cdot \boldsymbol{i}_S(t) \,, \quad (11)$$

$$p_S(t) = \boldsymbol{e}_{0\alpha\beta} \cdot K\boldsymbol{e}_{\alpha\beta} = K\boldsymbol{e}_{0\alpha\beta} \cdot \boldsymbol{e}_{\alpha\beta} \,. \quad (12)$$

Using (7), (10) and (12) gives

$$K = \frac{P_L}{e_{\alpha\beta}}{}^2 \,. \quad (13)$$

At last, compensation currents are obtained from

$$\boldsymbol{i}_C(t) = \boldsymbol{i}_L(t) - \boldsymbol{i}_S(t) \,, \quad (14)$$

$$\boldsymbol{i}_C(t) = \boldsymbol{i}_L(t) - K\boldsymbol{e}_{\alpha\beta} \,. \quad (15)$$

The compensation blocks are shown in Fig. 2. After compensation, the source supplies a constant instantaneous power with the same value of load power. However, Akagi

et al [21] had introduced the method which uses mapping matrices as follow

$$\begin{bmatrix} i_{C0} \\ i_{C\alpha} \\ i_{C\beta} \end{bmatrix} = \frac{1}{e_0 e_{\alpha\beta}^2} \begin{bmatrix} e_{\alpha\beta}^2 & 0 & 0 \\ 0 & e_0 e_\alpha & -e_0 e_\beta \\ 0 & e_0 e_\beta & e_0 e_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p}_{L0}(t) \\ \tilde{p}_{L\alpha\beta}(t) \\ q_{L\alpha\beta}(t) \end{bmatrix}. \quad (16)$$

Although original p–q theory compensates the oscillatory terms of load power; against the new vectorial method, it could not omit neutral current.

Moreover, second strategy is used to omit load reactive power and consequently increase the power factor. In fact, source current gets collinear to its voltage. The source provides just the load real power, but its instantaneous amount will not be constant after compensation [28]. However, the results of two mentioned strategies are identical if source voltages are sinusoidal and balanced [22]. In this case, current vector should be in phase with the voltage vector, so

$$\boldsymbol{i}_S(t) = G\boldsymbol{e}_{0\alpha\beta}, \quad (17)$$

G is a constant and from (10) and (11)

$$G = \frac{P_L}{e_{0\alpha\beta}^2}. \quad (18)$$

Now, like the later strategy compensation currents can be easily found from (14) which are explained in (17) has been shown in Fig. 3

$$\boldsymbol{i}_C(t) = \boldsymbol{i}_L(t) - G\boldsymbol{e}_{0\alpha\beta}. \quad (19)$$

Recently, due to arousing the application of different power electronic equipments, harmonic distortions get well-known topic in load compensation and power quality field. Thus, another objective is needed to consider for correcting non-sinusoidal and unbalanced currents [29–31]. The resulting currents should be sinusoidal, balanced and in phase with voltage positive sequence fundamental component in general.

Here, positive sequence fundamental component of voltage should be considered instead of voltage vector itself; so, $\boldsymbol{i}_S(t)$ and $\boldsymbol{e}_{\alpha\beta1}^+$ must satisfy relations

$$\boldsymbol{i}_S(t) = H\boldsymbol{e}_{\alpha\beta1}^+, \quad (20)$$

$$\begin{bmatrix} i_{S0} \\ i_{S\alpha} \\ i_{S\beta} \end{bmatrix} = H \begin{bmatrix} 0 \\ e_{\alpha1}^+ \\ e_{\beta1}^+ \end{bmatrix}, \quad (21)$$

where H, $e_{\alpha1}^+$ and $e_{\beta1}^+$ represent a constant value and positive sequences fundamental component of voltage vector in $0\alpha\beta$ axis, respectively. Also, E_1^{+2} is the square root of voltage positive sequence fundamental component root mean square (RMS) value which will be used. As the

same as pervious strategies, H is obtained from (10) and (20) and taking into account this relation

$$p_S(t) = \boldsymbol{e}_{0\alpha\beta1}^+(t) \cdot \boldsymbol{i}_S(t). \quad (22)$$

Thus

$$H = \frac{P_L}{E_1^{+2}}. \quad (23)$$

The compensation current vector is obtained as follow and its block is illustrated in Fig. 4

$$\boldsymbol{i}_C(t) = \boldsymbol{i}_L(t) - H\boldsymbol{e}_{\alpha\beta1}^+. \quad (24)$$
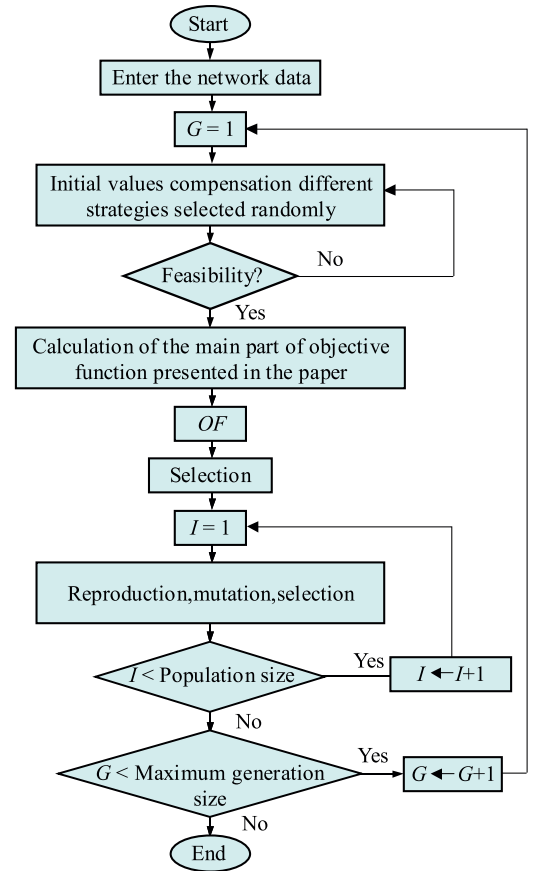

Fig. 5. Flowchart of the optimization process based on the genetic algorithm (GA)

4 OBJECTIVE FUNCTION

In electrical distribution networks, loss, PF, VP and THD are some important system characteristics. Therefore a new objective function has been proposed. As the costs of compensators are critical constraint in system designing, a penalty factor in basis of compensators number is added to objective function.

At first, the system parameters should be normalized and then each of them will come with an appropriate coefficient. The mathematical expressions of parameters

Table 1. Network lines impedances

	Resistance (Ω)	Reactance (Ω)
Line 1	0.291	0.887
Line 2	0.3	0.9
Line 3	0.372	0.911
Line 4	0.385	0.92
Line 5	0.323	0.903
Line 6	0.385	0.92
Line 7	0.621	1.54
Line 8	0.901	2.312
Line 9	0.372	0.911

Table 2. Voltage profiles and THDs of different uncompensated loads

Phase	A	B	C
Voltage Profiles			
Line 1	0.888	0.892	0.873
Line 2	0.933	0.922	0.903
Line 3	0.958	0.954	0.958
Line 4	0.895	0.879	0.871
Line 5	0.947	0.946	0.928
THDs			
Line 1	0.32	1.3	1.62
Line 2	4.86	10.1	6.16
Line 3	0.16	1.28	1.62
Line 4	0.78	3.66	2.5
Line 5	1.96	3.08	3.76

Table 3. Active and reactive power and power factor of different compensated loads

	Load 1	Load 2	Load 3	Load 4	Load 5
P (kW)	103	111	133	159	68
Q (kVar)	164	3.5	182	91.5	33
PF	0.532	0.999	0.59	0.867	0.9

Table 4. Five terms of the objective function

Index	LN	PFN	VPN	THDN	X
Normalized Value	0.515	0.324	0.042	0.432	0.4

normalization are
normalized total loss (TL)

$$L_{\mathrm{N}} = \frac{TL_0 - TL_c}{TL_0}, \qquad (25)$$

normalized voltage profile (VP)

$$VP_{\mathrm{N}} = \frac{VP_c - VP_0}{VP_0}, \qquad (26)$$

normalized power factor term (PF)

$$PF_{\mathrm{N}} = \frac{PF_c - PF_0}{PF_0}, \qquad (27)$$

normalized THD term

$$THD_{\mathrm{N}} = \frac{THD_0 - THD_c}{THD_0}. \qquad (28)$$

Where 0 and c subscripts represent the values of each parameters before and after compensation respectively. All of these positive-effect terms improvement makes objective function greater, in contrast there is a constraint factor that limits the objective function. This limitation term is cost term which is defined when one compensation is added to power system. In fact, costs of installation and application of APFs as compensation blocks play a negative-effect role in defined objective function. Thus, cost term is explained as

$$\text{Cost term:} \quad X = \frac{Number\ of\ Compensators}{Total\ Number\ of\ Available\ Palces} \qquad (29)$$

All above mentioned terms come together with weight coefficient ω_n to build main objective function (OF)

$$OF = -(\omega_1 L_{\mathrm{N}} + \omega_2 VP_{\mathrm{N}} + \omega_3 PF_{\mathrm{N}} + \omega_4 THD_{\mathrm{N}}) + \omega_5 X. \qquad (30)$$

In this paper, ω_1, ω_2, ω_3, ω_4 and ω_5 are taken 0.3, 0.1, 0.2, 0.2 and 0.2, respectively. Total losses will be considered with the highest amount of importance. Therefore, the optimal compensated network will have a suitable condition in the viewpoint of cost. Also, *PF* and *THD* terms come with a great amount of coefficient because of their effects in the power quality and the satisfaction of consumers.

Now, the genetic algorithm is used to find the optimum allocation of different compensation strategies indicated in Fig. 5. In this flow chart, parameters I and G present the population and generation number, respectively. Also the feasibility of solutions are checked on the basis of constraints exist in the optimization problem.

5 SIMULATION RESULTS

To apply the proposed method, a 5-bus typical power system is simulated in MATLAB Simulink as shown in Fig. 6. In Table 1 the impedances of the lines are presented. As shown in this table, there are 9 transmission lines in this network. The impedances of the network lines affect some system characteristics such as voltage profile and power loss. The voltage profile and THD of loads are demonstrated in Table 2. The detailed information on power factor, active and reactive power in system buses are presented in Table 3.

It is possible to find the critical loads in basis of different indices. Three loads have critical THD (load 2, Load 4 and Load 5) due to electrical switching. Two loads (Load 1 and Load 4) at the end of the system have critical voltage profile because of the voltage dropping, and
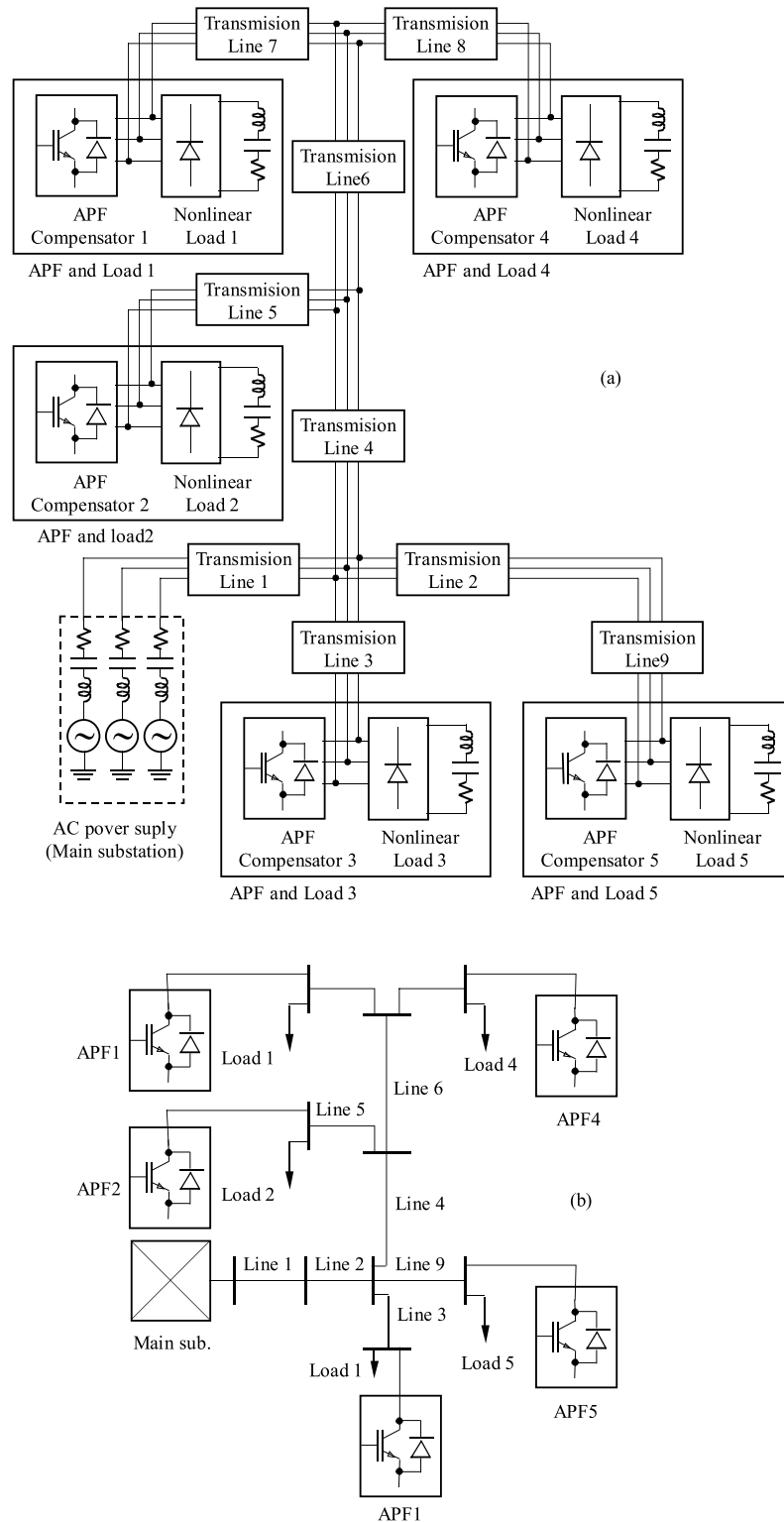
Fig. 6. Electrical diagram of the test system: a — three lines diagram, b — single line diagram

three loads consists of small PF (Load 1, Load 3 and more or less Load 4) as the great ratio of load reactive power requirement to load active power. Furthermore, 98.4 kW (approximately 12.4 % of total loads apparent power or 17.1 % of total loads active power) are wasting across the lines. The purpose is to provide an appropriate system with the proper amount of four above mentioned important system parameters.

To find the optimal allocation for each compensation strategy, the flowchart shown in Fig. 5 is used. By using genetic algorithm with 30 generation and 10 populations size the value of objective function (OF) is obtained -0.3099. Other parameters of GA such as elite count, crossover fraction of reproduction and migration fraction are selected 2, 0.8 and 0.2, respectively. In the optimum solution for compensation strategies allocation, the val-
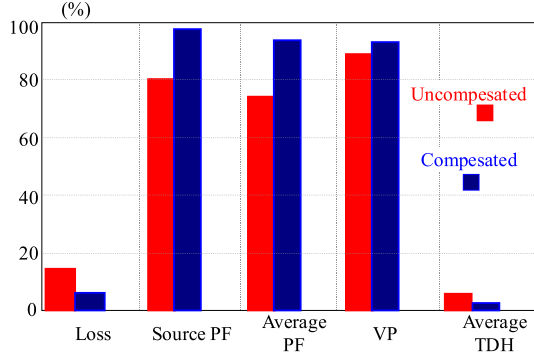
Fig. 7. Bar chart of system characteristics uncompensated and compensated

Table 5. Loads voltage profiles and THDs after optimal placing of different compensating strategies

Phase	A	B	C
Voltage Profiles			
Load 1	0.934	0.934	0.926
Load 2	0.958	0.957	0.951
Load 3	0.988	0.989	0.987
Load 4	0.929	0.926	0.922
Load 5	0.974	0.974	0.97
THDs			
Load 1	0.8	0.26	0.66
Load 2	1.14	1.82	0.94
Load 3	0.32	0.2	0.3
Load 4	0.32	0.86	0.88
Load 5	1.36	1.72	0.98

Table 6. Active and reactive powers and power factors of 5 loads after optimal placing of different compensating strategies

	Load 1	Load 2	Load 3	Load 4	Load 5
P (kW)	114.5	159	148.5	188	102.5
Q (kVar)	-5	45	49.5	-29.5	42
PF	0.999	0.962	0.949	0.988	0.925

Table 7. Comprehensive values before and after compensation of loads

	Total loss (kW)	Source PF	Average PF	Average VP	Average THD
Uncompensated	98.4	0.814	0.774	0.917	2.877
Compensated	47.7	0.995	0.962	0.955	0.837

Table 8. THD of the source-side

Phase	A	B	C	Average
Uncompensated	1.1408	3.474	2.7212	2.4452
Compensated	0.7584	0.97912	0.32	0.6856

ues of L_N, PF_N, VP_N, THD_N are 0.515, 0.324, 0.042, 0.432 as shown in Table 4.

Calculating the objective function by optimum values of the introduced parameters following (30) gives $OF = -0.3099$.

The optimized solutions for compensations are expressed as follows:

Load 1: strategy 3
Load 2: strategy 2
Load 3: strategy 3
Load 4: strategy 2
Load 5: needs no compensation

The simulation results demonstrate a great improvement in the amount of power factor and voltage profile, also a noticeable decrease in total loss and loads THDs which are indicated for each phase of the loads in Tables 5 and 6.

By this set of compensations, system total loss decreases to 48.5 percent of its pervious value which can be very considerable achievement. The improvement of each system parameters are indicated as normalized values in Table 7 for compensated and uncompensated conditions. Besides, Fig. 7 represents a comparison between the uncompensated and compensated values of system parameters. The average values of different loads power factors and voltage profiles increase to 0.962 and 0.955, respectively, as shown in Table 7. Also, the average value of loads *THD* is decreased to 29 % of its pervious amount. It should be noted that in Table 7, the values are corresponded to average values of different loads, although in Table. 8, the values are related to the source side.

Since the electrical parameters of Load 1 side are worse than other load sides, for instance, the current waveforms of Load 1 side under the uncompensated and compensated conditions are presented in Fig. 9. The other load sides current waveforms are not presented because they are similar to ones belong to Load 1 side. Moreover, the analytical conclusions and improvements of studied values such as THD, voltage profile, *etc* are completely presented. The current curves for each load point in the uncompensated and compensated conditions are presented in Figs. 9–11.

As indicated in Figs. 7-11, it can be noticed that for three different phases of each load, there is a great improvement on currents waveform. Therefore, THDs have been considerably decreased to near 25 % of their uncompensated values. It is very efficient especially for critical loads on the basis of harmonic distortions and improves power quality of a distribution system. Also, the decrease in currents RMS values is obviously shown. So, it affects on amounts of network losses. The total loss of the selected network approximately decreases to half of its pervious value. Thus, cost and failure rate of power system minimized. The APFs in distribution networks by optimized compensation strategies allocation is same as redundant lines. Therefore, the system reliability improvement could be achieved.

The voltage profile values of each load are presented in Fig. 10. As shown, without any compensation, Load 1 and Load 4 have the critical voltage drop. It should be noted that after compensation in accordance to optimum solution, the compensated values demonstrate a great
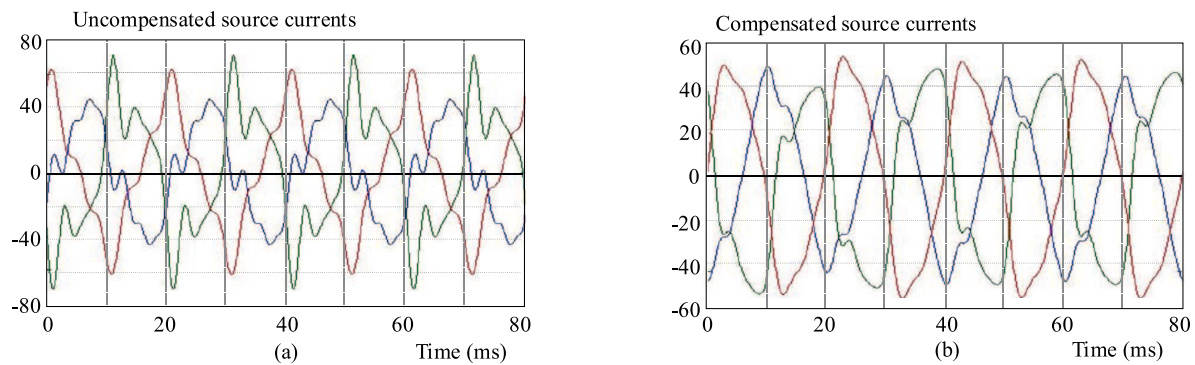
Fig. 8. Three-phase currents of source side : a — Uncompensated, b — Compensated source
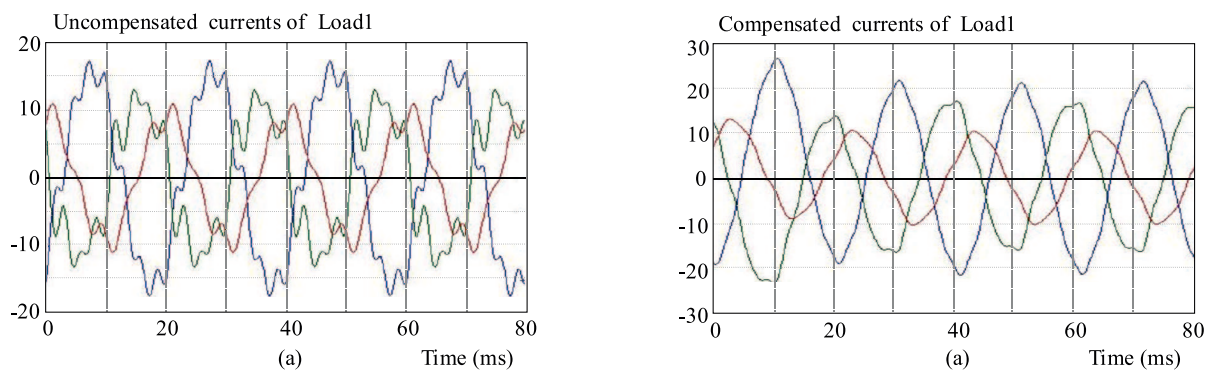

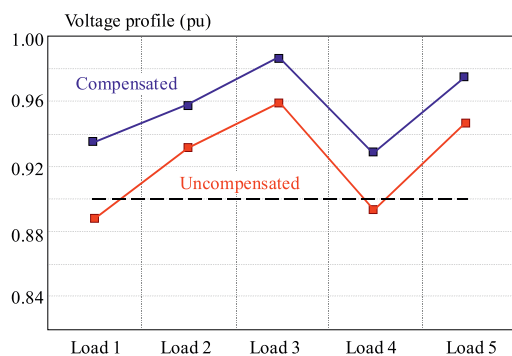**Fig. 9.** Three-phase currents of Load_1: a — Uncompensated, b — Compensated

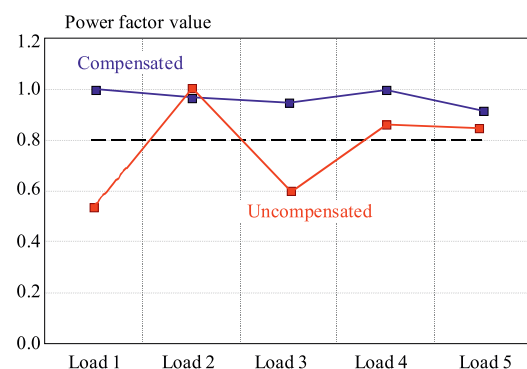**Fig. 10.** Compensated and uncompensated voltage profiles in load points

Fig. 11. Compensated and uncompensated power factor in load points

improvement and all loads are satisfied in the view point of voltage profile.

In Fig. 11, the power factor (PF) improvement of Load 1 and Load 3 from the critical condition to desire one are demonstrated. It is due to the decrement of phase shift between each phase voltage and current vectors. Therefore, consumers' power costs are decreased and power quality is improved.

5 CONCLUSION

The compensation of power losses and harmonics in distribution systems are interested in recent researches. Although, improving the power factor and voltage profile in different point of network is other interested fields. Active power filters (APFs) are power compensators to

improve the above parameters. There are several control strategies in order to operate APFs. Constant power, unity power factor and unbalanced and non-sinusoidal are commonly strategies used to control APFs. In this paper, three compensation strategies are simulated in MATLAB simulink toolbox in basis of vectorial representation instantaneous reactive power theory. The vectorial representation simplifies the implement of different strategies against the mapping matrices method.

The placement and compensation strategy of APFs affects their performances. Therefore, a novel objective function has been proposed. This objective function concluding five terms: normalized power losses, normalized voltage profile, normalized power factor, normalized THD and number of APFs. Genetic algorithm has been used to solve the optimization problem. The proposed method to evaluate the optimized APFs allocation illustrates this

method's performance in order to improve the system characteristics.

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