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Analysis of Voltage Profile And Its Improvement In Harmonic Included Distribution Systems

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***Abstract*—with consider to importance of power quality in power systems especially in distribution systems and with increasing application of electronic devices which have higher sensitivity to feeded powers quality, in this paper voltage profile in distribution systems has been paid attention. Improvement of voltage profile by various type of capacitor placement and effects of applying these methods on networks voltage profile has been depicted. These methods have been compared to each other and the best method has been selected for this affair. For achievement precise result harmonic load flow was performed on case study that was IEEE 37 node test feeder.**

Keywords-voltage profile; reactive power; power quality; harmonic; distribution systems

I. INTRODUCTION

Application of non-linear loads which are the most important harmonic generation sources has been grown increasingly in recent years. Electric furnace and power electronic converters are examples of such devices. Generated harmonics which flow in network impedances cause voltage harmonics and reduce power quality of network. Loss increase , failing of capacitor banks, life reduction of electrical equipments, Disturbance in correct performance of control and protection systems and resonance between different harmonics are some effects of this phenomena. To reduce of harmonic effects and voltage profile deviation in distribution networks, reactive power injection can be used as a useful approach. Injection process includes locating and determination of needed reactive powers value, which cause losses reduction. Improvement in voltage profile and ability of using of maximum capacity of network equipments, losses reduction in distribution system by capacitor placement have been studied in many researches. Some of these works finds the the optimum point with comparing all of the feasible points [1]. Also classic methods such as gradient based approach are used for calculation of optimal power value of needed power injection. This problem has been solved with other optimization methods such as simulated annealing [2].Genetic algorithm because of its ability to solving nonlinear and discrete problems proposed to solving this problem. This problem has been performed with load loss reduction purpose or cost reduction purpose [3, 4]. But voltage profile has been less attended as fitness function specially with considering voltage harmonic component. In this paper the aim is comparison of various type of capacitor placement for improvement of voltage profile. Many of reactive power planning are based on frequency main component, but because of harmonic component increase in power networks and their effects on voltage profile and losses, harmonic disturbances must be more attended. In this paper reactive power planning in present of unbalanced loads are described initially then problem formulation with fitness function introducing and constraints are discussed. Finally various type of capacitor placement with voltage profile fitness function are performed and best type of placement is selected. Advantage of each type has been described in the end. Results have been shown on IEEE 37 node test feeder.

II. REACTIVE POWER PLANNING

Nowadays reactive power planning is one of important factors in design and exploitation of power systems. Consumption growth lead to losses growth. So finding methods that can keep system voltage in permissible limits and decrease losses synchronously is essential. This affair is performed by network reactive power control usually. Expansion and large dimensions of distribution networks and power transfer through long lines cause great voltage drops in lines. Also with ever-increasing electronic devices applications power quality in load point must be improved from voltage and frequency aspects. Because voltage and frequency fluctuations can be very harmful for consumers reactive power control is one of best methods for good power quality achievement. This can be performed by reactive power injection in some substations with parallel capacitors or reactors or by other methods such as generator voltage changing, synchronous condenser installation in network and change in auto transformers tap. In this method voltage profile, power factor and voltage stability are improved in addition to losses decreasing. Loads usually are feed radially

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in distribution networks from sub transmission substations so effective approach for optimization of reactive power in distribution systems is capacitors placement. Improper selection of location and value of capacitor lead to voltage profile deviation in substations and increase transmitted reactive power. This subject in networks with unbalanced loads and harmonic component is more important.

III. GENETIC ALGORITHM THEORY

The GA is an optimization method based on evolution adaptations in nature. The GA works with a population of individuals (chromosomes) which each individual stands for a solution. Each part of chromosomes (genes) stands for special variable of mentioned problem. New generation is produced with considering individuals fitness function and genetic operators (selection, crossover and mutation) and individual's fitness improve through the algorithm iterations.

Stopping criteria determine the causes of the algorithm stopping and include two parts. In this resarch algorithm will terminate if each of these conditions is satisfied:

- Performance of algorithm up to 5000 iterations.
- If there is no improvement in the best fitness value for 1500 generations.

IV. FITNESS FUNCTION

Fitness function which have been used in various papers are different subsequently their results are different but in many of these papers the aim is losses reducing. In networks with unbalanced and non linear loads feeders voltage improvement is more important especially in feeders with great voltage drop. Hence in this research fitness function is voltage profile improvement in network. Fitness function is defined as (1) which is a criteria of feeders voltage deviation from their nominal value.

$$F = \sum_{i=a,b,c} \sum_{j=1}^{n} \sqrt{(1-V_j^i)^2} \qquad V_j^i = \sqrt{\sum_{h=1}^{h_{\max}} (V_j^{i,h})^2} \tag{1}$$

i	phases indice
j	nodes indice
n	number of substations in network
V_i^h	hth voltage harmonic component in node i
V_i	voltage in node i
$h_{\max}$	upper considered harmonic level

V. CONSTRAINTS

Problem such as reactive power planning have many constraints. This constraints can be included equality and inequality constraints as follow:

Nodal active and reactive power balance equations are defined as in (2) and (3).

$$P_{Gi} - P_{Di} - \sum_{j \in N(i)} P_{ij} = 0 \tag{2}$$

$$Q_{Gi} - Q_{Di} - \sum_{j \in N(i)} Q_{ij} = 0 \tag{3}$$

$$V_{j\min}^i \le V_j^i \le V_{j\max}^i \tag{4}$$

$$Q_{G\min} \le Q_G \le Q_{G\max} \tag{5}$$

Where

P_{Gi}, P_{Di}	Generated and consumed active power in node i
P_{ij}, Q_{ij}	Generated and consumed reactive power in node i
$N(i)$	Nodes connected to node i
m	Number of all lines in network

VI. HARMONIC LOAD FLOW IN RADIAL DISTRIBUTION SYSTEMS

Conventional load flow methods such as Quasi-Seydal encounter with limitations such as convergence problem. In this method with decreasing lines reactance to resistance ratio convergence speed decreases severely. Even in networks which their X and R value are near to each other divergence is occurred. A load flow method especially adapted for radial distribution systems was used in this research. Initially all feeders voltage assumed to be 1 pu. Line current harmonic component is calculated using this voltages and nodes active and reactive powers in each harmonic level then total line current are calculated and is used for calculation of active and reactive losses in lines. Total losses of network is equal to sum of all lines losses. Current in slack feeder is calculated according to (6) and (7) [5, 6].

$$I^i = \sqrt{\sum_h (I^{i,h})^2} \tag{6}$$

$$I^{i,h} = \left(\sum_{i=1}^{n} P^{i,h} + P_{loss}^{i,h}\right) - j\left(\sum_{i=1}^{n} Q^{i,h} + Q_{loss}^{i,h}\right) \Big/ {E_S^{i,h}}^{*} \tag{7}$$

Where:

$\sum_{i=1}^{n} P^{i,h}$	System total load in hth harmonic in phase i.
$P_{loss}^{i,h}$, $Q_{loss}^{i,h}$	System total losses in hth harmonic in phase i
${E_S^{i,h}}^{*}$	Conjugate voltage of phase i, in hth harmonic in slack feder.

Calculation continues and voltage drop and current in each line obtained from slack feeder to end and new voltage of nodes achieved finally. When this cycle complete once total losses is calculated from (8) to (10) and is compared with previous cycle losses. This process continues till losses difference in two successive cycles be less than permissible tolerance.

$$loss_k^h = \begin{bmatrix} I_k^{a,h} \\ I_k^{b,h} \\ I_k^{c,h} \end{bmatrix}^T \times \left[Z^h\right] \times \begin{bmatrix} I_k^{a,h} \\ I_k^{b,h} \\ I_k^{c,h} \end{bmatrix}^* \tag{8}$$

$$P_{loss}^{i,tot} = \sum_h P_{loss}^{i,h} \tag{9}$$

$$Q_{loss}^{i,tot} = \sum_h Q_{loss}^{i,h} \tag{10}$$

Where:

$\left[Z^h\right]$ network impedance matrix in hth harmonic level

VII. STUDY CASE

The case study in this research is IEEE 37 node test feeder that has been shown in Fig. 1

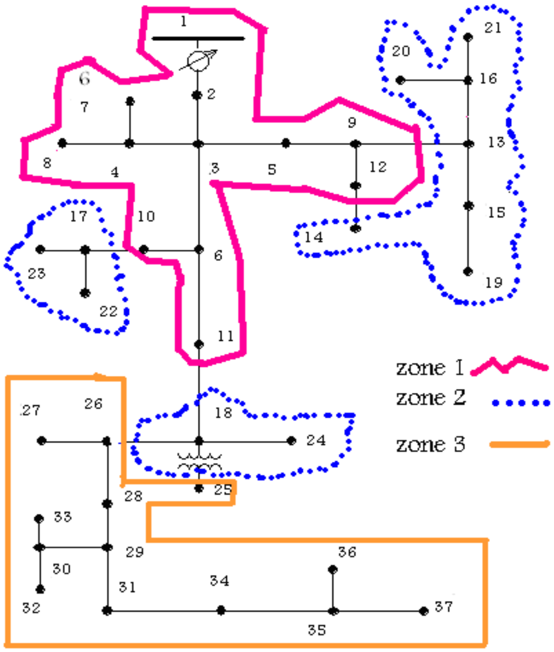

Figure 1. IEEE 37 node test feeder and selected zones for capacitor placement in each state

This feeder is an actual feeder located in California. The characteristics of the feeder are:

- All line segments are underground
- All loads are "spot" loads and consist of constant PQ, constant current and constant impedance
- The loading is very unbalanced

Although there are very few three-wire delta systems in use, there is a need to test software to assure that it can handle this type of feeder [7].

VIII. RESULTS

In this research in order to improvement of voltage profile reactive power injection was considered in four states as follow:

1. optimal location and determination of reactive power injection value in networks first one threeth nodes.(zone1)
2. optimal location and determination of reactive power injection value in networks middle one threeth nodes.(zone2)
3. optimal location and determination of reactive power injection value in networks last one threeth nodes.(zone3)
4. optimal location and determination of reactive power injection value in networks whole nodes.

The zones discussed in above four states have been shown in Fig. 1. Location and value of capacitors has been searched synchronously which is considered in chromosome. Chromosome used here has 12 gene that six first gene stand for location of capacitor installation and next six gene stands for injected reactive power value in selected nodes. Fig. 2 show chromosome schematically. Numbers of capacitors was selected six in each state. Initial network voltage profile has been shown in Fig. 3. Network has a good voltage profile initially but with reactive power injection it can be improved again. Selected feeders and injected reactive power value in each state have been depicted in table I.

N.N stands for selected node number and Q stands for injected reactive power and are in KVAR.

L_1	L_2	L_3	L_4	L_5	L_6	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6

Figure 2. Selected chromosome for this problem with 12 gene

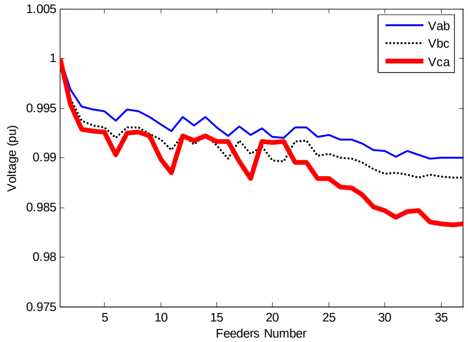

Figure 3. networks initial voltage profile

TABLE I. NUMBER OF SELECTED NODES AND VALUE OF INJECTED REACTIVE POWER IN EACH STATE

State 1		State 2		State 3		State 4	
N.N	**Q**	**N.N**	**Q**	**N.N**	**Q**	**N.N**	**Q**
2	532	13	543	27	577	2	562
5	-575	14	-560	29	-543	7	-566
7	-70	17	-72	31	-271	14	-27
8	22	20	46	33	290	21	32
10	-293	22	-598	36	-385	23	-389
11	-592	23	-322	37	-599	31	-556

Voltage profile curve after network modification for states 1 to 4 have been shown in Fig. 4 to Fig. 7 respectively.

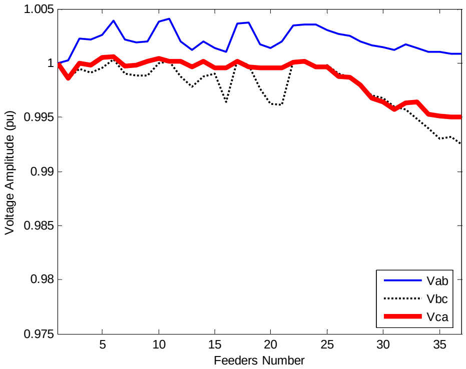

Figure 4. networks voltage profile after optimal capacitor placement in zone 1

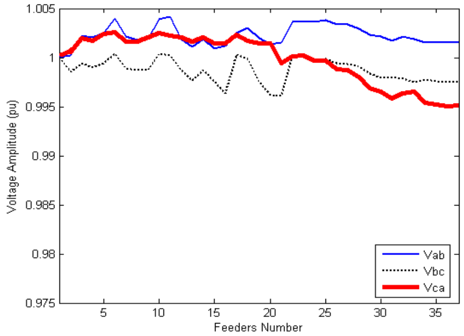

Figure 5. networks voltage profile after optimal capacitor placement in zone2

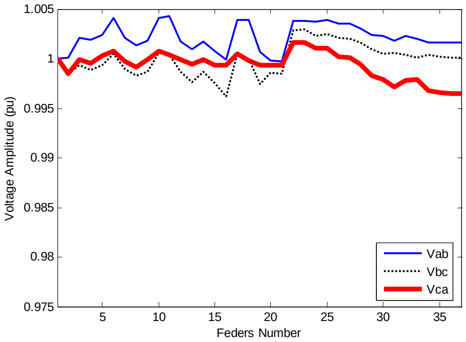

Figure 6. networks voltage profile after optimal capacitor placement in zone3

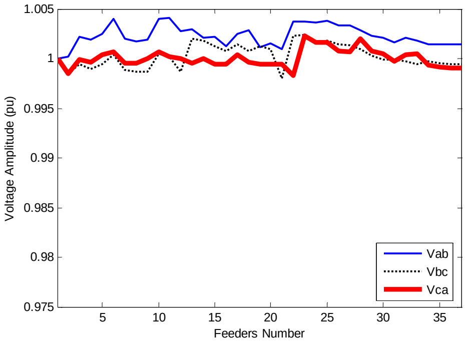

Figure 7. networks voltage profile after optimal capacitor placement in entire of network

With consider to importance of economic aspect of problems and amount of investment for optimization of each plan it is necessary to compare these states from economic aspect. Table II Shows amount of investment and amount of losses after and before reactive power injection and also total economic save in each state.

With definition a new quality factor (QF) which include economic saves factor and a criteria of voltage profile, we can classify these states. If this factor has greater value it means that state is better solution for our purpose. T stands for Economic save resulted from network modification(reactive power injection). And T_{ideal} is same T in ideal condition that losses be zero.

$$QF = (\alpha \frac{T}{T_{ideal}} + \beta(1 - Vp)) \tag{11}$$

$$T=(S-I) \tag{12}$$

I stands for investment and include total cost of reactive power injection in each state (40$ for 1 kvar injected reactive in iran).

S stands for economic saves consequent from losses reduction within period of five years.(50 $ for 1 Mwh electric energy)

This factor in ideal condition must be equal $\alpha + \beta$ and in worst condition is equal zero. α and β are coefficient dependent to our purpose and importance of each factor for us. These coefficients can be alter from each plan to another. T_{ideal} in our case study is equal to 12264000$

If the both factors (voltage profile and economic save) have same priority for us we can consider $\alpha = \beta$. If the economic saves be more important than voltage profile we can suppose $\alpha \rangle \beta$ and vice versa. The absolute value of α and β is not important because our purpose is comparison of these states and this would be same in all states. What is important for us is ratio of $\frac{\alpha}{\beta}$ which determine relative importance of economic save and voltage profile in our plan.

LB = Losses percentage before network modification
LA = Losses percentage after network modification
VP = Voltage profile criteria

Calculated QF1 in this table is based on $\alpha = \beta = 1$ and calculated QF2 is based on $\alpha = 0 \ \ \beta = 1$ and QF3 has calculated base on $\alpha = 1 \ \ \beta = 0$.

TABLE II. LOSSES AND FITNESS FUNCTION VALUE IN EACH STATE

	State1	**State2**	**State3**	**State4**
VP	0.04694	0.04721	0.04677	0.04583
LB (%)	5.6%	5.6%	5.6%	5.6%
LA (%)	3.79%	3.83%	4.06%	3.81%
I ($)	83360	86000	106600	85280
S ($)	3963900	3876300	3372600	3920100
T ($)	3880540	3790300	3266000	3834820
QF1	1.26947	1.26184	1.21953	1.26685
QF2	0.31641	0.30767	0.26630	0.31268
QF3	0.95306	0.95279	0.95323	0.95417

It is clear from QF3 (fitness function) values ,it is a criteria of voltage profile quality only, that for reach to best voltage profile state 4 is best method. State 3, 1, 2 are in next priority for this affair. If we compare these states base on economic save factor only i.e QF2, the state 1 is best solution and states 4, 2 and 3 are in next priority. Finally if our criteria for states comparison be QF1 (include both voltage profile quality criteria and economic saves criteria with equal importance for plan) the state 1 is best solution and states 4, 2, 1 are in next positions.

In addition to voltage profile losses value is an important factor after network modification in each state. . It is obvious from table that states 1, 4 , 2 And 3 have less losses after reactive power injection respectively.

Obtained results for minimum of objective value in sate 4 for each generation in 5000 iterations have been shown in Fig. 8.

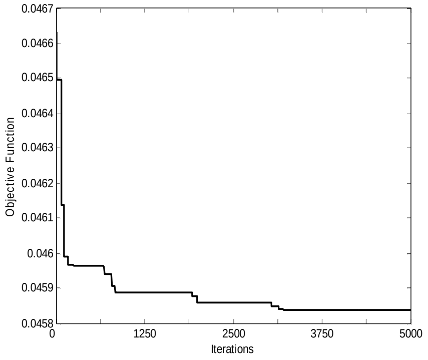

Figure. 8. Improvement of best fitness function of each generation in GA in state 4

IX. CONCLUSION

This paper paid attention to importance of voltage profile and its improvement in present of unbalanced loads and harmonic component were considered. Reactive power injection in various nodes is implemented. To improvement of voltage profile genetic algorithm that has ability of obtaining global optimal solution was used. Three zones include first one threeth, middle one threeth, last one threeth nodes were selected for location and determination of capacitor values in that zones. In forth state GA searched its solutions from entire network nodes. A new quality factor for capacitor placement was defined that can be included both criteria of voltage profile quality and economic save criteria. For three kind of this definition with varius coefficients this problem on this case study was solved and varius satates result was compared eachother. Obtained results showed that first state is best method base on both QF1 and QF2 and base on QF3 the fourth state is best solution. Also losses value was calculated for each state and was compared with each other.

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