Optimum location and sizing of passive filters in distribution networks using genetic algorithm

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***Abstract*-The harmonic distortion of voltage has became an important subject in power quality, especially after use of power electronic equipment and nonlinear loads. Simple method to limitation of harmonic distortion is using of passive filters. The objective of this paper is to determine the location and size of passive filters in distribution networks economically, by using genetic algorithm. With using of genetic algorithm and new coding here some of other methods limits for passive filters locations are removed. The purpose of the genetic algorithm is to minimize the cost of passive filters and, at the same time, to reach the harmonic limitations defined by standard IEEE-519. This algorithm is applied to IEEE 13-bus distribution network and the results are shown, finally**

I. INTRODUCTION

Whit increasing use of power electronic equipment and nonlinear loads, the level of voltage harmonic distortion in distribution networks are significantly increasing. As harmonics propagate through the system, they result in increased losses and possible equipment loss-of-life. Also Overcurrents or overvoltages resulting from resonances can damage equipment. Additionally, harmonics can interfere with control, communication, and protective equipment. With this reasons different research institutes have studied about the proper limitation of harmonic disturbance levels and released different standards.

Among the several methods used to reduce these harmonic disturbances, the more employed are the tuned passive filters due to their simplicity and economical cost.

The important problem of using passive filters are determining location and sizing of them, which is reach standard levels of harmonic distortion with applying minimum cost of passive filters [1, 2].

In reference [3], the objective is to propose a new approach for designing a passive LC filter of the full-bridge rectifier by using genetic algorithms (GAs). The objective of the fitness function in the GA program is to find out the maximum PF of the ac mains with the smallest inductor value.

Reference [4] describes the application of genetic algorithm to calculate the R-L-C parameters of passive harmonic filters that may be installed in the customers' houses. The main goal is to minimize the harmonic impedance in some specific frequencies and to maximize the fundamental frequency impedance in order to minimize losses.

Reference [5] presents a method that applies the Combinatory optimization by microgenetic algorithms for the location and optimum project of passive harmonic filters. The minimization of total voltage harmonic distortion and active power losses has been used as objective function. In this reference, the problem consists of planning two passive harmonic filters, whose harmonic tuning orders are 4.7 and 6.6, respectively.

Reference [6] describes the application of genetic and a microgenetic algorithm to the problem of locating and sizing passive filters in an electric network affected by harmonic disturbances. In this work, the objective function to be minimized is the value of voltage harmonic distortion. In this reference, the input data are the number of filters and the relevant order of these filters.

In this work by using genetic algorithm and new coding, location and sizing of passive filters is determined so with installing them the standard levels for voltage distortion is achieved with minimum cost of passive filters. By comparing with other methods the number and harmonic order of passive filters is automatically determined in this work.

Standard limitation that is considered here is standard IEEE-519 for harmonic limitation.

In the next part of this paper firs modeling of passive filters, based of new coding and finally the result of applying the new method to IEEE- 13-bus distribution network will be illustrated.

II. PASSIVE FILTERS

The most common type of passive filter is the single-tuned "notch" filter. This is the most economical type and is frequently sufficient for the application. The notch filter is series-tuned to present low impedance to a particular harmonic current and is connected in shunt with the power system (usually near the loads that produce harmonics). Thus, harmonic currents are diverted from their normal flow path on the line through the filter.

Shunt passive filters depend on three design parameters: 1- the tuning harmonic order, 2- the quality factor Q, the filter band and the residual harmonic voltage depend on Q, 3- the capacitor rating at the fundamental frequency.

Inductive reactance and resistor values at the fundamental frequency are:

$$X_L = \frac{Xc}{n^2} \qquad R = \frac{X_L}{Q}$$

This is important point that the values of capacitor rating at the fundamental frequency and the quality factor are discrete. The typical value of quality factor is between 30 and 60 for single-tuned "notch" filter. Moreover, the standard IEEE for capacitor rating is available.

Based of new coding, in this work for each candidate buses for installing passive filter, four filter branches are considered, that each of these four filters is used for different harmonic orders. The load buses that produce harmonics are considered as candidate buses. For each of four filters seven bits are considered in chromosome. The first bit shows presence or absence, next three bits show the quality factor and the latest three bits show the capacitor rating. With this coding method the chromosome size is equal to 7*4*candidate buses.

III. OBJECTIVE FUNCTION

Objective function is the cost of filter branches. This cost contains the cost of capacitors, inductors, and resistors. So:

$$fitfun = cprice + lprice + rprice$$

Where, cprice, lprice and rprice respectively are price of capacitors, inductors and resistors. The cost of capacitors at different voltage level in distribution networks is available. The cost of filter inductors does not vary greatly for units of different rating. The cost approximation used in the analysis is of the form:

$$\text{Inductor cost=UK+UL (MVAR)}$$

Where UK is a constant cost component and UL is the inductor incremental cost per MVAR rating. These values relate to the single phase and must be converting to the three phase.

The power rating of the resistor necessary for Q-adjustment in each filter branch will affect the cost to some extent. However, the nominal resistance of the unit is difficult to predict in a general analysis, because it depends on the natural Q factor of the inductor. For this reason, and because the cost of an air-cooled resistor is small compared with that of the other components, a constant cost per resistor is allocated in the analysis [1].

For eliminating the individual that don't observe the harmonic limitations, a penalty factor is used.

IV. CONSTRAINS

Based on standard IEEE-519, the value of THD at PCC (Point of Common Coupling) in distribution networks below 69 kV must be lower than 5% and the value of IHD lower than 3%. Also practically, the values of capacitor ratings and quality factors are discrete.

V. GENETIC ALGORITHM

The GA is a search mechanism based on the principle of natural selection and population genetics. At the beginning of GAs, representations for possible solutions, which are often called chromosomes or individuals, must be developed. A chromosome consists of a series of genes which can be represented by binary codes. Different combinations of genes form different chromosomes. Each chromosome is a possible solution of the problem. The set of chromosomes is called the population of the generation. Chromosomes in a generation are forced to evolve toward better ones in the next generation by three basic GA operators, reproduction, crossover, and mutation, and the problem-specified fitness function.

In reproduction, a number of selected exact copies of chromosomes in the current population become a part of the offspring. In crossover, randomly selected subsections of two individual chromosomes are swapped to produce the offspring. In mutation, randomly selected genes in chromosomes are altered by a probability equal to the specified mutation rate. For a binary coding gene, it means that digit 1 becomes digit 0 and vice versa.

The fitness function, also called the objective function, is an evaluation function that plays the role of the environment to distinguish between good and bad chromosomes. Only a certain number of chromosomes screened and selected by the fitness function can survive and pass their genes to the next generation.

Each chromosome of the current population is evaluated by the fitness function and some good chromosomes are selected. Then a new population will be generated by using the three basic GA operators, i.e., reproduction, crossover, and mutation.

A. *Reproduction*

The reproduction of new individuals is made as follows:

- Find the total fitness of the population:

$$f_{total} = \sum_{i=1}^{n} f_i$$

Where:

f_i : Fitness of each individual $i(1,2,...,n)$

n : Number of individual in the population

- Calculate the probability of reproduction for each individual $i(1,2,...,n)$.

$$p_i = \frac{f_i}{f_{total}}$$

- Round p_i $i(1,2,...,n)$ and copy each individual i for p_i times at mating pool

- Enter three random individuals instead of last three individuals of population

B. *Crossover*

The crossover operator follows:

- Select individuals two by two respectively
- Select a filter branch characters in random

Replace it by relative filter branch of next individual by the probability of crossover (p_c)

C. *Mutation*

The mutation operator follows:

- Select individuals respectively

Reverse the bits relative to absence or presence of filter branches by the probability of mutation (p_m)

VI. CASE STUDY

This paper uses an IEEE standard distribution network to perform the study. This network consists of 13 buses and is representative of a medium-sized industrial plant. The plant is fed from a utility supply at 69 KV and the local plant distribution system operates at 13.8 KV [7].

The system is shown in figure 1. More information on this network can be obtained at *http://www.ee.ualberta.ca/pwrsys/harmonics.html.*

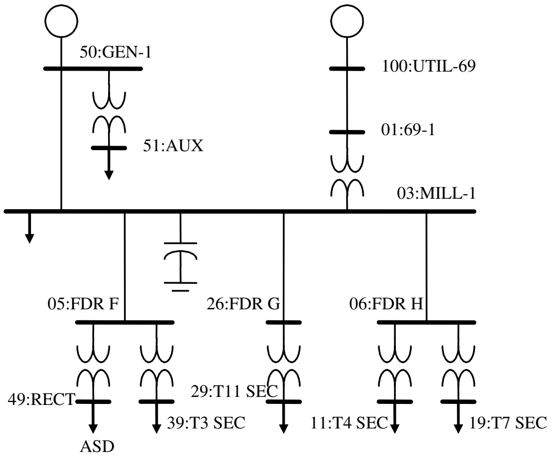

Figure 1: IEEE 13-buses standard network

In this paper in addition to 49:RECT, the 29:T11SEC and 51:AUX is considered also as a nonlinear load.

Standard rating of single-phase capacitors and their costs that released by ABB (according to IEEE and IEC standard), are shown in following table:

Table 1
Standard single-phase capacitor ratings and their costs

XC (KVAR)	PRICE ($)
50	550
100	625
150	705
200	790
300	950
400	1155
500	1315
600	1455

In this paper the value of UK and UL is considered 500$ and 90 ($/MVAR) respectively. p_m , p_c and the size of population are considered 0.15, 0.75 and 10 respectively.

VII. SIMULATION RESULT

Passive filters locate at the primary side of load transformers (PCC's) generally, thus in this problem, the candidate buses for filters are 50:GEN-1, 05:FDR F and 26:FDR G.

The program result is shown in table 2 and Table 3 shows the THD values of buses before and after filtering.

Convergence curves of the algorithm for five individual runs are shown in figure 2.

Table 2
Simulation result

Filter branch	1
Tuning order	7
Location	26:FDR G
XC (KVAR)	150
Q	50
C (µF)	2.1
L (mH)	68.8
R (Ω)	3.63

Table 3
THD of buses before and after filtering

bus	Initial THD (%)	Final THD (%)
50:GEN-1	10.56	2.48
03:MILL-1	10.93	2.55
51:AUX	9.95	7.72
100:UTIL-69	1.34	0.32
01:69-1	1.36	0.33
05:FDR F	10.93	2.55
49:RECT	11.04	10.23
39:T3 SEC	9.86	2.32
26:FDR G	10.92	2.56
29:T11 SEC	11.12	10.41
06:FDR H	10.93	2.55
11:T4 SEC	10.55	2.47
19:T7 SEC	9.96	2.34

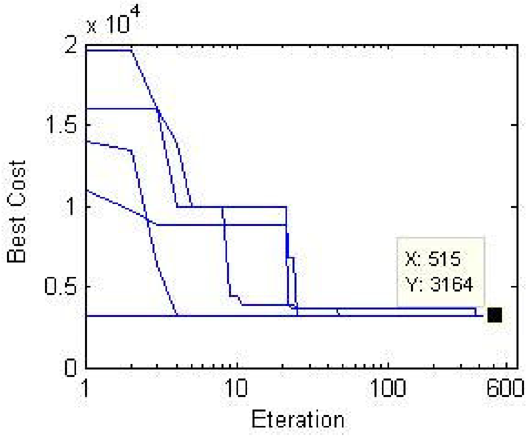

Figure 2: Convergence curves for five algorithm runs

Curve A and B in fig.2 show the changing of transfer impedance between 26:FDR and 29:T11 SEC buses respectively before and after installing passive filter. Because of using of power factor correcting capacitor in network, as shown in fig.3 network has a resonance frequency near the 7th harmonic order. After installing filter this frequency change to two new resonance frequencies far from 7th harmonic order.

In designing passive filters for a network it must be considered that after installing filters new resonance frequency near the nonlinear loads order don't be appeared. However, with using genetic algorithm by consideration a penalty factor in fitness function appearing of this new resonance frequency is prevented.

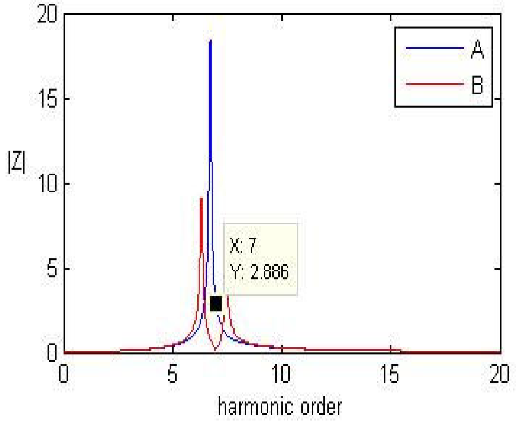

Figure 3: Harmonic impedance before (A) and after (B) filtering

VIII. CUNCLOSION

This paper deals with determining the location and size of passive filters by genetic algorithm, economically. The algorithm constrains are the limitation of harmonic distortion that define by standard IEEE-519. The algorithm determines the number, harmonic order, size and location of passive filters to reach the IEEE standard..

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