Passive Power Filters Harmonic and Power Quality Optimization Analysis Using Multiobject Optimization Algorithm

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Abstract.
Continuous technological development facilitates the increase in the number of nonlinear loads that significantly affect the power quality in a power system and, consequently, the quality of the electric power delivered to other customers. One of the most common methods to prevent adverse effects of nonlinear loads on the power network is the use of passive filters. Design of such filter can be regarded as a multi-criterial optimisation task, to which genetic algorithms can be employed. Watching recent tendencies in science can be observed an increasing number of "artificial intelligence" applications to practical solutions. It has been therefore decided to apply genetic algorithms (GA) to passive power filter design as an example of GA usefulness for technical issues. The paper presents passive filter structures designed using a program developed by the author in the MATLAB environment employing genetic algorithm. Two methods of approaching the design goal are presented - traditional and GA.

Keywords: passive filters, power system harmonics, genetic algorithms.

I. Introduction

Decrease in the value of harmonic voltages in the public HV network to the requirements established in [1] is a topical problem in Russia. A great number of nonlinear loads, including those of large capacity consume nonsinusoidal current from the network thus distorting the voltage waveform. The number of nonlinear loads will be rising each year since they represent high technology equipment which is increasingly widely used in all spheres of life. By virtue of some specific features of the Russian electric networks one of the most appropriate technical tools capable to decrease harmonic voltages is passive filter. Passive filters can be installed in the immediate vicinity of nonlinear loads if the nonlinear loads are concentrated. In the case of distributed nonlinear loads passive filters can be applied on a centralized basis [2]-[5]. The authors of the publications [2], [3] used the firstorder filter for reduction of harmonic voltages on a centralized basis. This filter is effective at tuned frequency. The other types of passive filters, namely, second-order filter, third-order filter and C-type filter decrease harmonic voltage not only at the harmonic they are tuned to but also the harmonic of a higher order. Therefore, it is interesting to consider application of these types of filters to reduction of harmonic voltage on a centralized basis. This problem was already considered in [3], [4]. However, the problem of determining the optimal filter parameters was solved incompletely. Enumeration method was used for solving the optimization problem of calculating the parameters of passive filters in previous works.

II. Literature Survey

Different researchers have studied the proper limitation of harmonic disturbance levels, and among several techniques used to reduce these harmonic disturbances, the most frequently employed are the passive filters, due to their simplicity and economical cost [9]-[14]. Passive filters have many types that can achieve different frequency response characteristics. In the literature, C-type filters have three advantages more than conventional passive filters. Firstly, Ctype filters have low fundamental frequency power loss compared to other types of the filters; hence they are considered energy efficient passive filters. Secondly, they can damp resonance that may occur with the utility system. Thirdly, C- type filters are considered low cost filters that can serve well as low or high passive filters [5]. Accordingly, many studies present the C-type filter as a reasonable passive solution. The C-type filter combined with an active filter for cost-effective compensation was considered in [12], with the aim to minimize the power rating of the active filter by optimizing parameters of the C-type filter using the grid search method as the optimization method. Additionally, optimal sizing of the parameters of the C-type passive filter for minimizing total voltage harmonic distortion using FFSQP (FORTRAN feasible sequential quadratic programming) was presented in [1]. Recently, three C-type filter design studies [13], [7], [14] are presented for the effective utilization of cables and transformers under non-sinusoidal conditions, maximization of the load power factor, and maximization of the loading capabilities of the transformers supplying non-linear loads, respectively.

III. Research Motivation

Harmonics and reactive power regulation and guidelines are upcoming issues and increasingly being adopted in distributed power system and industries. Vital use of power electronic appliances has made power management smart, flexible and efficient. But side by side they are leading to power pollution due to injection of current and voltage harmonics. Harmonic pollution creates problems in the integrated power systems. The researchers and engineers have started giving effort to apply harmonic regulations through guidelines of IEEE 519-1992. Very soon customers have to pay and avail the facility for high performance, high efficiency, energy saving, reliable, and compact power electronics technology. It is expected that the continuous efforts by power electronics researchers and engineers will make it possible to absorb the increased cost for solving the harmonic pollution.

IV. PASSIVE FILTER

The passive filters are used to mitigate power quality problems in six-pulse ac-dc converter with R-L load. Moreover, apart from mitigating the current harmonics, the passive filters also provide reactive power compensation, thereby, further improving the system performance. For current source type of harmonic producing loads, generally, passive shunt filters are recommended [3]. These filter apart from mitigating the current harmonics, also provide limited reactive power compensation and dc bus voltage regulation. However, the performance of these filters depends heavily on the source impedance present in the system, as these filter act as sinks for the harmonic currents. On the other hand, for voltage source type harmonic producing loads, the use of the series passive filters is recommended [3]. These filters block the flow of harmonic current into ac mains, by providing high impedance path at certain harmonic frequencies for which the filter is tuned. Moreover, the harmonic compensation is practically independent of the source impedance. But, passive filter suffer due to the reduction in dc link voltage due to the voltage drop across the filter components at both fundamental as well as harmonic frequencies.

This chapter presents a detailed investigation into the use of different configurations of passive filter such as passive shunt filter and passive series filters. The advantages and disadvantages of both configurations are discussed. It is observed that both these configuration fail to meet the IEEE standard 519 guidelines under varying load conditions. A novel configuration of passive hybrid filter (a combination of passive shunt and passive series filter) is designed and developed for power quality improvement. The main attraction of this configuration is that it can achieve the improved power quality even under varying load conditions, its rating is less and it can maintain that dc link voltage regulation within certain limits. The prototypes of these passive filters are developed and that test results are presented to verify the simulated results. Finally, a comparison of different power quality aspects in different configurations of passive filters is also presented for ac-dc converter with R-L load.

V. **Classification Of Passive Filters**

Depending on the connection of different passive components, the passive filters can be broadly classified in three categories as given below.

Passive Shunt Filter

Fig.2. shows the schematic diagram of a passive shunt filter connected at input ac mains of sixpulse ac-dc converter with R-L load. This is the most commonly used configuration of passive filters. In this configuration different branches of passive tuned filters (low pass and high pass) tuned for the more dominant harmonics are connected in parallel with the diode rectifier with RL load. It consists of a set of low pass tuned shunt filters tuned at 5th and 7th harmonic frequencies and high pass tuned for 11th harmonic frequency. This passive filter scheme helps in sinking the more dominant 5th and 7th and other higher order harmonics and thus prevents them from flowing into ac mains. The diversion of harmonic current in the passive filter is primarily governed by the source impedance available in the system. The higher value of source impedance offers better performance of the passive filter.

Passive Series Filter

For voltage source type of harmonic loads (such as diode rectifier with R-L load filter), passive series filter is considered as a potential remedy for harmonic mitigation. Here, the different tuned branches of passive filters are connected in series with the supply and the diode rectifier. Fig.1 shows the schematic diagram of a passive series filter connected at input ac mains. It consists of a set of low block tuned shunt filter tuned at 5th and 7th harmonic frequencies and high block tuned filter for 11th harmonic frequency. These passive filters blocks most dominant 5th , 7 th and other higher order harmonics and thus prevents them from flowing into ac mains. Here, the performance of the series filter is not much dependent on the source impedance. However, it results in reduction in dc bus voltage due to voltage drop across filter components.

Passive Hybrid Filter

The use of passive shunt filter creates the problem of voltage regulation at light loads. It also increases the dc voltage ripple and ac peak current of the rectifier. On the other hand, passive series filter suffers from lagging power factor operation as well as the voltage drop across the filter components both at fundamental frequency as well as harmonic frequencies. To overcome these drawbacks, a combination of both these configurations is presented as passive hybrid filter. This configuration is able to supplement the shortfalls of both these passive filters and simultaneously it results in improvement in harmonic compensation characteristics for varying load condition even under stiff and distorted ac mains voltage.

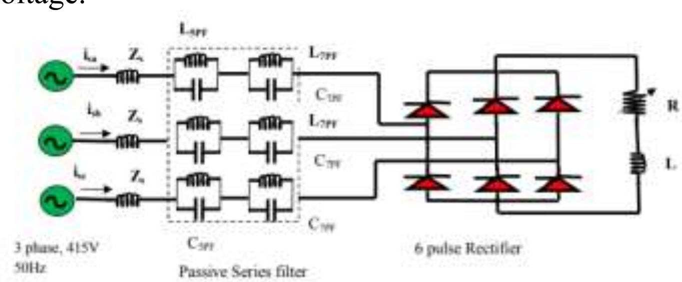

Fig.1 Schematic diagram of a ac-dc converter with R-L load and passive series filter at input.

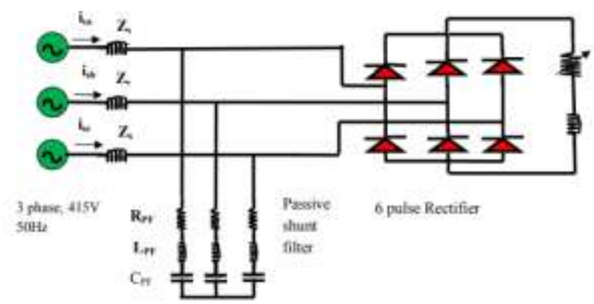

Fig.2. Schematic diagram of a six pulse ac-dc converter with R-L load and passive shunt filter at input

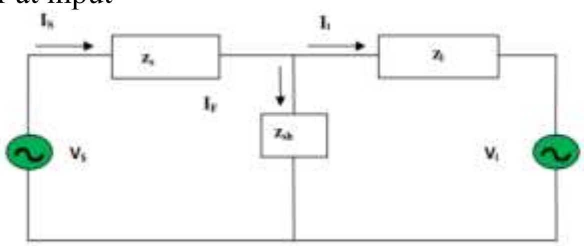

Fig.3 Equivalent circuit diagram of passive tuned shunt filter based configuration.

VI. Proposed Methodology Genetic Algorithm

Genetic Algorithms (GA) are stochastic global search method, mimicking the natural biological evolution. Genetic Algorithms idea first introduced by J.H. Holland in the late sixties and seventies of the last century. He noted that natural evolution is done at the chromosome level, and not directly to individuals. In order to find the best individual, genetic operators apply to the population of potential solutions, the principle of survival of the fittest individual. In every generation, new solutions arise in the selection process in conjunction with the operators of crossover and mutation. This process leads to the evolution of individuals that are better suited to be the existing environment in which they live. AG popularity is due to its features:

- they don't process the parameters of the problem directly but they use their coded form,
- they start searching not in a single point but in a group of points,
- they use only the goal function and not the derivatives or other auxiliary information,
- they use probabilistic and not deterministic rules of choice.

These five features consists in effect on the usability of Genetic Algorithms and hence their advantages over other commonly used techniques for searching the optimal solution. There is a high probability that the AG does not get bogged in a local optimum. An important term in genetic algorithms is the objective function. The objective function is the basis of assessment of the quality of all individuals in the population and the creation of a new generation. Each iteration of the genetic algorithm creates a new generation.

Principle of operation

Genetic algorithms provide potential solutions to a given problem and the choice of final solution leaves you. Where a particular problem is not single solution as in the case of a multi-criteria optimization, the AG are potentially useful to identify those alternatives. Figure 1 shows the basic block diagram of a Genetic Algorithm.

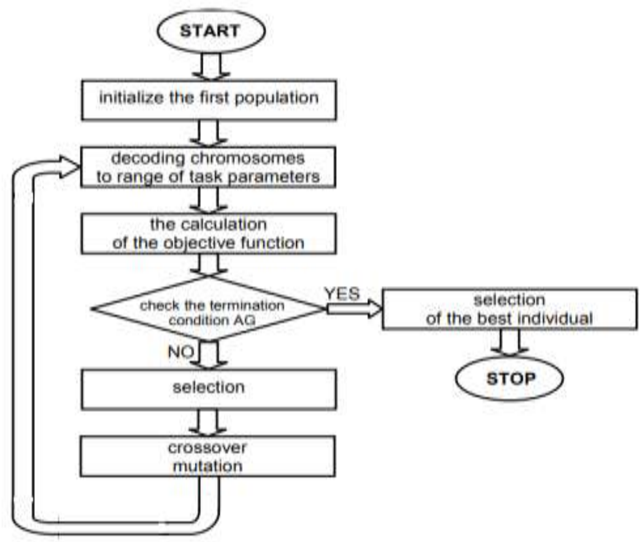

Fig. 4. Block diagram of the basic Genetic Algorithm (GA)

Since the first research on the form of genetic algorithms and components underwent modifications and the current form of the basic genetic algorithm includes:

- initialization of the first population,
- decoding the chromosomes to the task parameters,
- determine the value of the objective function for each individual,
- check the condition of ending the algorithm
- selection,
- crossing and mutation.

Initialize the first population

Genetic algorithms operate on a population of potential solutions. Each subsequent generation creates the child population, after which it is expected to make it better than their parents. The first population is generated completely randomly. But before it is created, you must specify the basic parameters of the Genetic Algorithm, such as population size (the number of individuals in the population), the number of task parameters (decision variables) and the length of the chromosome (code length of each of the decision variables).

Decoding

Genetic algorithm able to work properly it is necessary to decode genotypes (chromosomes) to phenotype, that is, the range of parameters the task. The AG is possible to use different coding methods. It is preferable to use a Gray code, as it has a fixed value in terms of Hamming distance between two consecutive values. Each two adjacent values differ by the value of one bit. Each parameter task Genetic Algorithm has allowed range of variation.

The objective function

On the basis of decoded chromosome representation it is possible to assess the fit of individual members of the population to the "environment" task. This is done by the objective function, which is characterized by the individual adjustment of the space problem. In the real world, it can be the ability to survive in a particular environment. Therefore, the objective function establishes the basis for the selection of individuals to be included in the pool of parental during reproduction. The purpose of the objective function is to estimate the usefulness of an individual to the development of the population. The higher the value of the objective function, the individual is better, better adapted, which has a greater chance of survival. It is assumed that the objective function must be non-negative.

Condition for the end of the algorithm

AG work termination condition depends on the optimization task. The algorithm can finish their work, the objective function reaches its maximum value. Another way is to count the deviation of the objective function within the population. If it is small the algorithm terminates. The algorithm may end operation as such after a period of work or after the assumed number of iterations (generations).

Selection

The most important operator of genetic algorithm is to select individuals which will participate in the creation of a new generation. This choice is based on the objective function. The most adapted individual has the greatest opportunity to participate in the creation of a new population. There are many methods of selection. The most popular method is the method of selection based on the roulette wheel. For each individual assigned to a section of the roulette wheel size proportional to the value of the objective function of an individual (Fig. 2). Thus, the higher the value of the objective function, the larger section of the roulette wheel corresponds to an individual. All the roulette wheel is the sum of the objective function value of all individuals in the population.

Crossover

This operator is used to differentiate the population by which each generation there are new individuals, different of individuals selected for the initial population. First randomly select two individuals from the pool of parents. If after checking the condition of crossover, crossing individuals are randomly selects the crossing point. The operation consists of replacing crossover of genetic material between chromosomes.

Mutation

After crossover operator each individual in the population is checked and undergoes mutations. Mutation probability is low. If individual is mutated, randomized gene is subject to this process. The operator changes the value of the gene mutation to the opposite, i.e. 0 is changed to 1 and 1 to 0. After these three genetic operators such as selection, crossover and mutation, the child population is obtained, which is better adapted than their parents, taking into account the average value of the objective function, which provides a better potential solutions to the task optimization.

Selected Filter Structures

The usefulness of the new method is illustrated by examples of designing selected filters' structures:

1. a group of single-tuned filters,
2. double-tuned filter,
3. Type filter.

The formulas quoted later, allow to set filters parameters with the simplistic assumption that the resistance of the filters are equal to zero. This assumption does not apply in the design of filters, using Genetic Algorithms.

VII. Result and Simulation

Passive harmonic filters are primarily harmonic control devices whose function is to avoid the circulation of distorted currents through the elements of the system, reducing the harmonic distortions of voltage in the bars. To evaluate the effect of filters on distortion rates, all possible operating scenarios of the system should be evaluated, including the L characteristic scenarios considered and another set of special system and load conditions. These special conditions may include variations in network impedance, different modes of operation of harmonic producing loads, tuning of filters, etc. They are non-characteristic operating states for which a daily operating time is not allocated, with impacts on energy calculations, power factor, etc., but with influence on the determination of harmonic distortion rates.

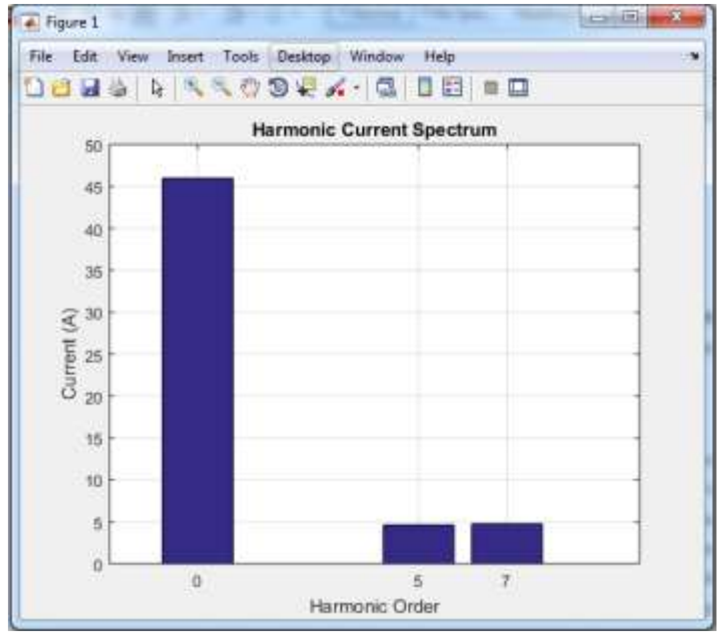

Fig. 5. Harmonics current.

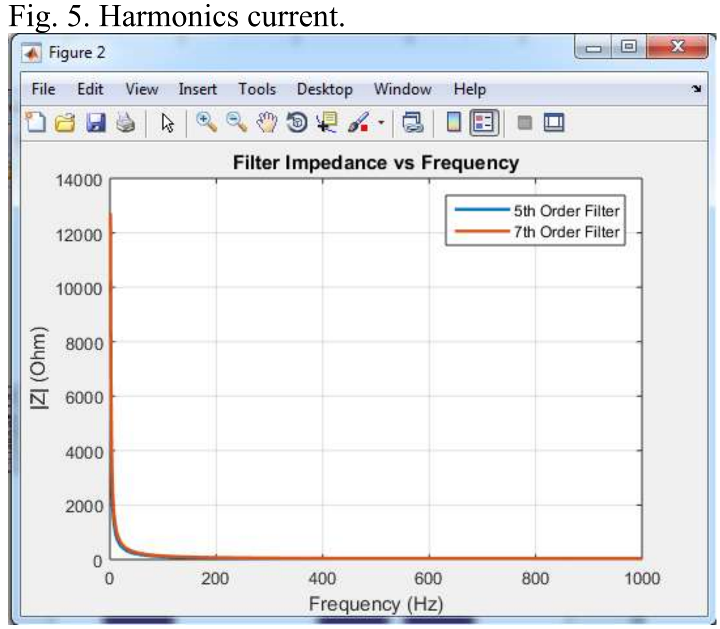

Fig. 6. Filter impedance.

Table 1: Genetic Algorithm Optimization Progress

Generation	**Function Evaluations (f-count)**	**Best Fitness f(x)**	**Mean Fitness f(x)**	**Stall Generations**
1	160	1407	1.11×10^4	0
2	240	1131	7202	0
3	320	1081	4581	0
4	400	919.5	2958	0
5	480	619	2319	0
6	560	503.6	1560	0
7	640	412.4	1097	0
8	720	403.6	1131	0
9	800	403.6	679.4	1
10	880	403.6	562.8	2
11	960	403.6	488.8	3
12	1040	402.8	445.3	0
13	1120	401.8	424.4	0
14	1200	401.8	415.0	1
15	1280	401.8	411.9	2
16	1360	401.8	408.0	3
17	1440	401.5	527.8	0
18	1520	401.5	501.7	1
19	1600	401.5	543.0	2
20	1680	401.3	478.9	0
21	1760	401.2	557.3	0
22	1840	400.8	456.3	0
23	1920	400.3	429.9	0
24	2000	400.3	404.9	1
25	2080	400.3	404.5	2
26	2160	400.3	404.2	3
27	2240	400.3	586.6	4
28	2320	400.3	482.8	5
29	2400	388.4	600.7	0
30	2480	388.4	569.5	1

Table 2: GA Optimization Progress per Generation

Generation	**f-count**	**Best f(x)**	**Mean f(x)**	**Stall Generations**
31	2560	377.4	708.5	0
32	2640	377.4	635.2	1
33	2720	377.3	748.1	0
34	2800	377.3	524.2	1
35	2880	377.3	688.7	2
36	2960	374.7	689.2	0
37	3040	374.7	735.6	0
38	3120	374.6	567.0	0
39	3200	374.6	598.0	1
40	3280	374.6	527.2	2
41	3360	374.6	755.5	3
42	3440	372.1	629.1	0
43	3520	372.1	779.9	0
44	3600	372.1	560.7	1
45	3680	372.0	669.7	0
46	3760	372.0	491.1	1
47	3840	372.0	697.9	2
48	3920	372.0	633.7	0
49	4000	372.0	828.9	1
50	4080	372.0	815.4	2
51	4160	371.3	620.2	0

52	4240	371.3	659.7	1
53	4320	370.6	540.4	0
54	4400	370.6	594.7	1
55	4480	370.6	541.2	2
56	4560	370.5	523.6	0
57	4640	370.5	509.9	1
58	4720	370.3	441.7	0
59	4800	**298.5**	456.5	0
60	4880	**298.3**	542.3	0

Table 3: GA Optimization Progress (Generation 61–90)

Generation	f-count	Best f(x)	Mean f(x)	Stall Generations
61	4960	298.3	731.6	1
62	5040	298.1	732.0	0
63	5120	298.1	878.2	1
64	5200	298.1	694.8	2
65	5280	298.1	520.0	3
66	5360	267.0	449.3	0
67	5440	267.0	360.2	0
68	5520	267.0	435.4	1
69	5600	267.0	406.4	2
70	5680	266.8	348.7	0
71	5760	266.8	352.5	1
72	5840	266.8	289.9	2
73	5920	266.8	286.0	0
74	6000	231.9	282.3	0
75	6080	231.9	316.7	1
76	6160	228.3	319.9	0
77	6240	228.3	355.9	1
78	6320	224.6	299.5	0
79	6400	224.6	311.9	1
80	6480	224.6	300.2	2
81	6560	221.8	252.1	0
82	6640	221.7	265.8	0
83	6720	221.6	259.3	0
84	6800	221.6	369.8	1
85	6880	221.6	359.5	2
86	6960	221.6	306.3	3
87	7040	221.0	298.8	0
88	7120	221.0	230.1	1
89	7200	221.0	237.4	2
90	7280	221.0	222.9	0

Table 4: GA Optimization Progress (Generation 91–100)

Generation	f-count	Best f(x)	Mean f(x)	Stall Generations
91	7360	221	222.3	1
92	7440	221	295.6	0
93	7520	221	305.0	0
94	7600	221	286.8	1
95	7680	221	304.	2

			9	
96	7760	221	297.3	3
97	7840	221	281.7	0
98	7920	221	270.2	0
99	8000	221	242.6	1
100	8080	221	288.1	0

VIII. CONCLUSION

The presented analysis THD and filer parameters optimized of group single-tuned, single branch passive filters, double-tuned filter and the filter design, demonstrate the genetic algorithm usefulness as a tool for optimisation and seeking for filters' parameters without the need for unnecessary simplifications that may lead to erroneous solutions. The use of genetic algorithm allows imposing constraints on the optimisation task, such as the maximum filter current and maximum voltages across the filter components, and enables the multi-criterial optimisation. All the above demonstrates the usefulness of this optimisation tool, particularly for extensive power systems.

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