

OPTIMAL DESIGN OF ACTIVE SHUNT FILTER USING PARTICLE SWARM OPTIMIZATION

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Abstract : This paper proposes an optimal design method for Active power filter set at normal supply voltage, to satisfy the requirements of harmonic filtering. Optimization modal for Active power filter is constructed. The PSO algorithm was developed to find optimal solution for the design of Active filter. This filter is applied to engineering laboratories and other R&D departments, Industries where single phase rectifiers are used which involves harmonic problems indicate the practicality of the proposed design method though at base level.

Keywords: PSO-particle swarm optimization, APF-active power filter.

I. INTRODUCTION

A power system has to deal with variety of non linear loads which introduces a significant amount of harmonics [1]. IEEE standard 519-1992 provides a guide line for the limitation and mitigation of harmonics. For low voltage systems Active power filters are better choice considering the cost and ratings of power electronic devices [2], [3] & [4].

The design of Active power filter is a complicated nonlinear programming [14]. Conventional trial and error methods based on engineering experience and simulation software's are commonly used but the results are not optimal in most cases. Basic nonlinear mathematical optimization techniques used sometimes may not converge and moreover they give approximated results in most cases. Genetic algorithms have been widely used but the computation and convergence burdens are disadvantages of this approach [5] & [6]. A design method using hybrid algorithm is more complex, involving mutation, cross over, migrant and accelerated operations.

This paper treated the optimal design of Active power filter[12],[13] as a single optimization problem with no constraints and an advanced particle swarm optimization algorithm is reported. The main objective is developed from the view point of improvement in power quality, to reduce harmonics on source side. The Active power filter proposed works to reduce the harmonics created by the rectifier circuit on the source side and hence improving the quality of power.

II.SYSTEM UNDER STUDY

Atypical 1-phase 230V, 50Hz system with nonlinear load as shown in fig1, was studied to determine the optimal design of active power filter. The nonlinear load is the single phase rectifier circuit which is commonly used in engineering laboratories, R&D Departments and many industries where 1- Φ AC to DC conversion is used, which pumps harmonics to the source with abundant harmonic currents, as shown in table1. The acceptable THD according to IEEE standards is shown in table1.

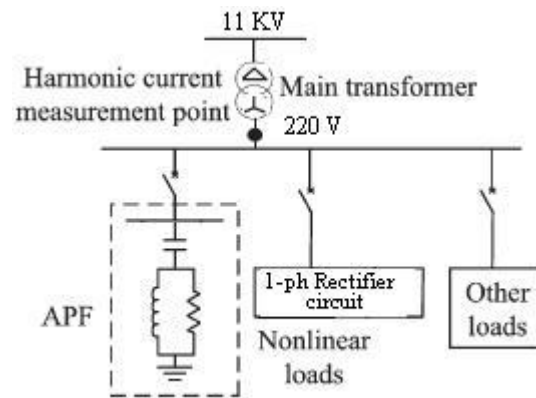


Figure 1 Single diagram of system for case studies

Table 1 THD in line and acceptable tolerances

	Measured Value	Accepted Value
THD	108%	<10%

The higher order harmonics are having very low magnitudes and can be neglected and so do the source voltage harmonics. For this system with non linear load as 1- Φ Rectifier circuit on the supply system the THD exceeds the tolerance limits and so filters must be installed to mitigate the harmonics sufficiently and to bring THD within acceptable limits. The higher order harmonics are having very low magnitudes & can be neglected and so do the source voltage harmonics. For this system with non-linear load as 1 rectifier circuit on the supply system the harmonic currents exceed the tolerance levels and so filters must be installed to mitigate the harmonic sufficiently to satisfy the international standards.

The present system under study is a general rectifier circuit used in laboratories experimental purpose. The non linear load considered is a rectifier circuit which pumps harmonics into the supply side in our present problem. In a single phase supply system even harmonics are absent and the presence of only odd harmonics can be felt. In this paper we consider a single phase rectifier circuit connected to a non-linear load and the harmonics due to this load is to be considerably reduced. Figure2 shows the circuit and fig3 shows single line diagram of a single phase active shunt filter respectively.

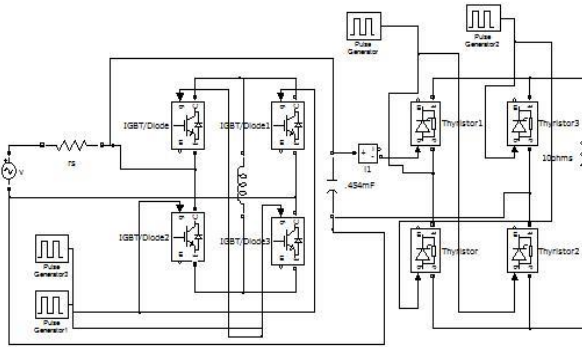


Figure 2 Single phase active shunt filter circuit diagram connected between source and nonlinear load.

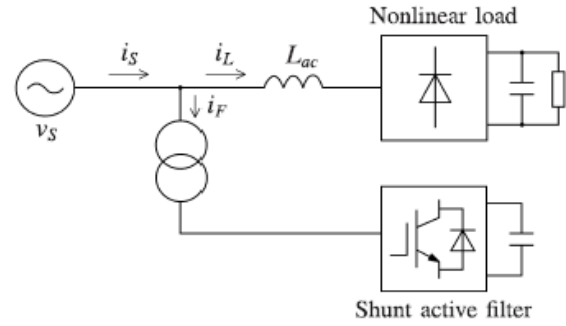


Figure 3 Single phase active shunt filter single line diagram

The filter circuit is made up of IGBTs because IGBT has the best qualities of both PMOSFET (high input impedance) and BJT (low on state power loss).

III.DESCRPTION OF OPTIMISATION PROBLEM

Current based compensation is classified as current harmonics compensation. For the current harmonics compensation, the active shunt filter is an ideal device, and considered most suitable because of its reduced cost caused due to the low rating of power electronics (typically 4%-5% of load). In this paper we consider an active shunt filter in order to reduce current harmonics due to a non linear load for a single phase supply system.

In the design of single-tuned filter, the parameters of L and C can influence the filtering performance, especially when the system frequency or the parameter of L or C changes, so it is necessary to choose optimal values for L and C. Figure4 shows single phase equivalent circuit of fig1 and fig5 shows Equivalent harmonic circuit of Active shunt filter.

Fig. 4 shows the single-phase equivalent circuits of the APF, assuming that the APF is an ideal controllable voltage source VAF and that the load is an ideal current source I_L . Z_S is the source impedance, Z_F is the total impedance of the APF, V_{pcc} is the voltage of the injected point, and K is the controlling gain of the APF [11]. The harmonic current I_{sh} into the system source is shown in the eq (4).

$$f_i = \frac{1}{2\pi\sqrt{L_i C_i}} \quad (1)$$

$$F(X) = \text{THD1}$$

$$\text{THD1} = \sqrt{\sum_{h=2}^N \left(\frac{I_{sh}}{I_{LH}} \right)^2}$$

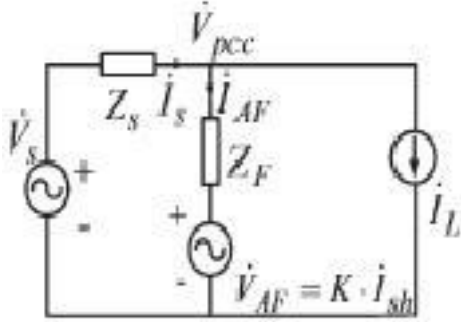


Figure 4 Single-phase equivalent circuit of Active shunt Filter

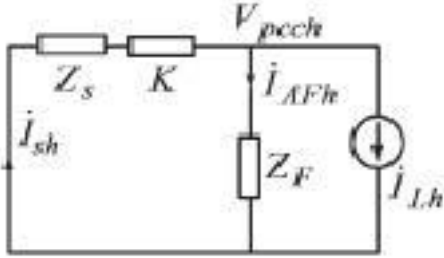


Figure 5 Equivalent harmonic circuit of Active shunt filter

$$I_{sh} = \left| \frac{Z_F}{K + Z_F + Z_s} \right| I_{LH}$$

Eq. (1) Eq. (2) Eq. (3) and Eq. (4) are used in the optimal design of active shunt filter [11] and the optimization is done here is unconstrained optimization. No cost parameters are included in optimal design of filter parameters as the inductance and capacitance used here are already economical and the main problem is to design optimal values of inductance and capacitance which will give minimum THD rather than the cost which are already economical.

IV. PSO METHOD

Two scientists namely Dr. Kennedy and Dr. Eberhart developed a PSO algorithm based on the behavior of individuals (i.e., particles or agents) of a swarm in the year 1995.

(2)

PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions called particles, fly through the problem space by following the current optimum particles.[7][9]&[10].

(3)

Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called *pbest*. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbors of the particle. This location is called *lbest*. When a particle takes all the population as its topological neighbors, the best value is a global best and is called *gbest*.

The particle swarm optimization concept consists of, at each time step, changing the velocity of (accelerating) each particle toward its *pbest* and *lbest* locations (local version of PSO). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward *pbest* and *lbest* locations.

In past several years, PSO has been successfully applied in many research and application areas. It is demonstrated that PSO gets better results in a faster, cheaper way compared with other methods.

Another reason that PSO is attractive is that there are few parameters to adjust. One version, with slight variations, works well in a wide variety of applications. Particle swarm optimization has been used for approaches that can be used across a wide range of applications, as well as for specific applications focused on a specific requirement.

An individual in a swarm approaches to the optimum or quasi-optimum through its present velocity, previous experience, and the experience of its neighbors. Thus, the particle swarm can be used to solve complicated optimization problems in power systems. In a physical N -dimensional search space, the position and velocity of the individual i are represented as the vectors $1, xGbest\ Xi = (xi1, xi2, \dots, xiN)^T$ and $Vi = (vi1, vi2, \dots, viN)^T$, respectively. Let $Pbesti = (xPbesti1, xPbesti2, \dots, xPbestiN)$ and $Gbest = (xGbest1, \dots, xGbestN)$ be the best position of an individual i and its neighbors' best position so far, respectively. By using this information, the updated velocity and position of individual i at iteration k are modified using the following equations:

$$V_{(K+1)i} = W.V_{Ki} + c1.rand1() \times Pbest_{Ki} - X_{Ki} + c2.rand2() \times Gbest_K - X_{Ki}$$

$$X_{(K+1)i} = X_{Ki} + V_{(K+1)i}, i = 1, 2, 3, \dots, M$$

Where M is the quantity of particles, $c1$ and $c2$ are weight parameters, w is the inertia weight, and $rand1()$ and $rand2()$ are random numbers between zero and one. The maximum allowed velocity V_{max} determines the searching granularity of space. X_{max} is the maximum allowed value for particle position. Generally, the relationship is set as follows:

$$V_{max} = K \cdot X_{max}, 0.1 < K < 0.2$$

Weight parameters $c1$ and $c2$ are scaling factors that determine the relative “pull” of P_{best} and G_{best} [8]. These are sometimes referred to as the cognitive and social rates, respectively. The best suggested values for $c1$ and $c2$ are 2.0. The inertia weight w resolves the tradeoff between the global

and local exploration abilities of the swarm. A large inertia weight encourages global exploration, while a small one promotes local exploitation. Obviously, varying w is suggested to obtain the best performance. In this paper, a linearly decreasing inertia weight with increasing iteration is adopted, as indicated in

$$W = W_{max} - ((W_{max} - W_{min}) / iter_{max}) \times iter$$

Where w_{max} and w_{min} are the initial and final values of w , respectively. $iter_{max}$ and $iter$ are the maximum and current iteration numbers, respectively.

The overall flowchart for the PPF design based on PSO is shown in figure below and was implemented using the popular software MATLAB/M file. Its algorithm is as follows:

Step 1) Initialize a group of particles while satisfying the constraints, including current THD, individual harmonics, fundamental reactive power compensation, and parallel and series resonance with system. Then, calculate the fitness of the initial particles.

Step 2) Update velocity and position of particles.

Step 3) Calculate the new fitness of the updated particles.

Step 4) Check whether the updated particles still satisfy the common constraints, including current THD, individual harmonics, fundamental reactive power compensation, parallel and series resonance with system, and the detuning effect constraints. If not, go to Step 7).

Step 5) Check whether the updated particles satisfy the acceptable-level constraints. If not, go to Step7).

Step 6) Update the P_{best} and G_{best} .

Step 7) Check whether the terminal criteria are satisfied. The terminal criteria can be defined as satisfying fitness value or maximum iteration steps. If not, go to Step2).

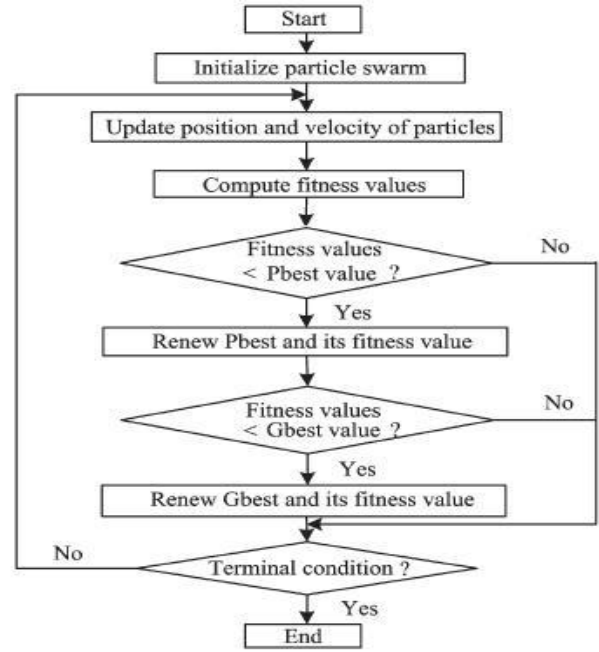


Figure 6 shows the flow chart for optimal design of APF based on PSO.

The below defined program is for unconstrained optimization based on the cost function defined by Eq. (2) Eq. (3) and Eq. (4)

PROGRAM

```
%% Particle Swarm Optimization Simulation
%% Initialization Parameters
```

```
clear
```

```
clc
```

```
iterations = 100;
```

```
inertia = 2.0;
```

```
correction_factor = 1.5;
```

```
swarm_size = 49;
```

```
% initial swarm position
```

```
index = 1;
```

```
for i = 1 : 7
```

```
    for j = 1 : 7
```

```
        swarm(index, 1, 1) = i;
```

```
        swarm(index, 1, 2) = j;
```

```
        index = index + 1;
```

```
    end
```

```
end
```

```
swarm(:, 4, 1) = 1500; % best value so far
```

```

swarm(:, 2, :) = 0;          % initial velocity
%% Iterations
for iter = 1 : iterations
    %evaluating position & quality
    for i = 1 : swarm_size
        swarm(i, 1, 1) = swarm(i, 1, 1) + swarm(i, 2,
1)/3.4;    %update L position
        swarm(i, 1, 2) = swarm(i, 1, 2) + swarm(i, 2,
2)/1.3;    %update C position
        L = swarm(i, 1, 1);
        C = swarm(i, 1, 2);
        num= (314.16*(L*0.001)*i);
        den=                                (0.36-
(0.8*98696.04*(L*0.001)*(C*0.000001)))+(314.16*(L
*0.001)*i));
        THD =sqrt((((num/den)^2)*(1.0245))-1);
    % fitness evaluation
        if THD < swarm(i, 4, 1)
    % if new position is better
            swarm(i, 3, 1) = swarm(i, 1, 1);
    % update best L,
            swarm(i, 3, 2) = swarm(i, 1, 2);
    % best C postions
            swarm(i, 4, 1) = val;
    % and best value
        end
    end
    [temp, gbest] = min(swarm(:, 4, 1));
    % global best position
    for i = 1 : swarm_size
    %-- updating velocity vectors
    %L velocity component
        swarm(i, 2, 1) = rand*inertia*swarm(i, 2, 1) +
correction_factor*rand*(swarm(i, 3, 1) - swarm(i, 1,
1)) + correction_factor*rand*(swarm(gbest, 3, 1) -
swarm(i, 1, 1));
    %C velocity component
        swarm(i, 2, 2) = rand*inertia*swarm(i, 2, 2) +
correction_factor*rand*(swarm(i, 3, 2) - swarm(i, 1,
2)) + correction_factor*rand*(swarm(gbest, 3, 2) -
swarm(i, 1, 2));
    end
    % Plotting the swarm
    clf
    plot(swarm(:, 1, 1), swarm(:, 1, 2), 'L') % drawing
swarm movements
    axis([-2 1000 -2 1000]);
    pause(.2)
    end
L

```

C
abs(THD)

After simulation using Matlab technique the final result obtained is the optimum values of L and C in an infinite set which are L= 574mH and C=454μF and the obtained THD for the corresponding values of L and C is 12% through PSO.

Putting these values in of system under study shown in fig2 and simulating the circuit, the THD thus obtained for these values of L and C is 0.35% through MATLAB. Hence, PSO method can be considered the efficient method for designing a power electronic system optimally.

The simulation results using PSO and Conventional methodologies have been compared and presented below.

Table 2 : DESIGN RESULTS OF ASF BASED ON PSO AND CONVENTIONAL METHODS

Design parameters	PSO method	Conventional method
L&C	L= 574mH C=454μF	L=100mH C=500 μF

Table 3 TOTAL HARMONIC DISTORTION WITH ASF BASED ON PSO AND CONVENTIONAL METHODS (the below results are taken for a thyristor firing of 120^0)

	PSO method	Conventional method
THD	0.38%	108%

V. MATLAB RESULTS

The following are the results obtained by simulating the shunt type active filter by using MATLAB

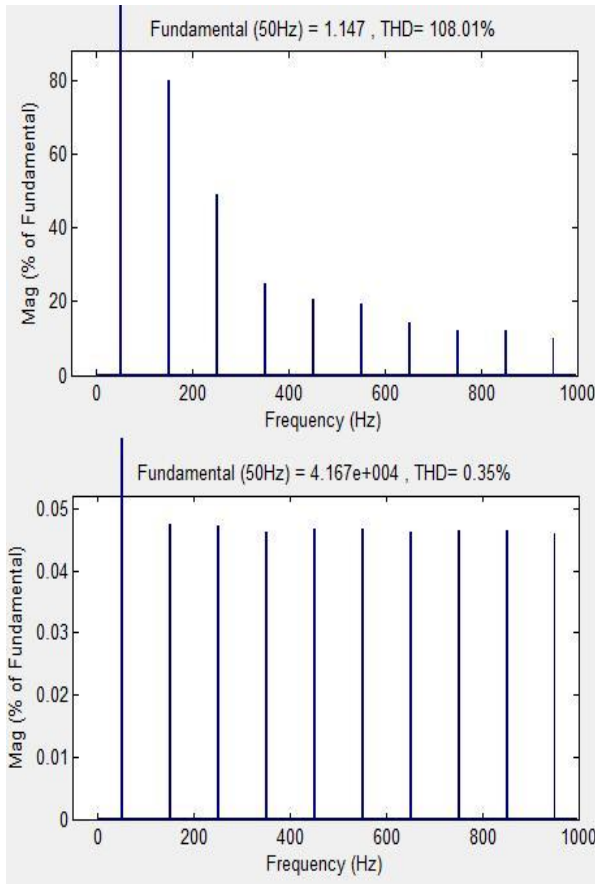


Figure 7 Fast Fourier measurement of THD for source current without and with filter (these results are taken keeping firing angle of thyristor bridge rectifier at 120^0).

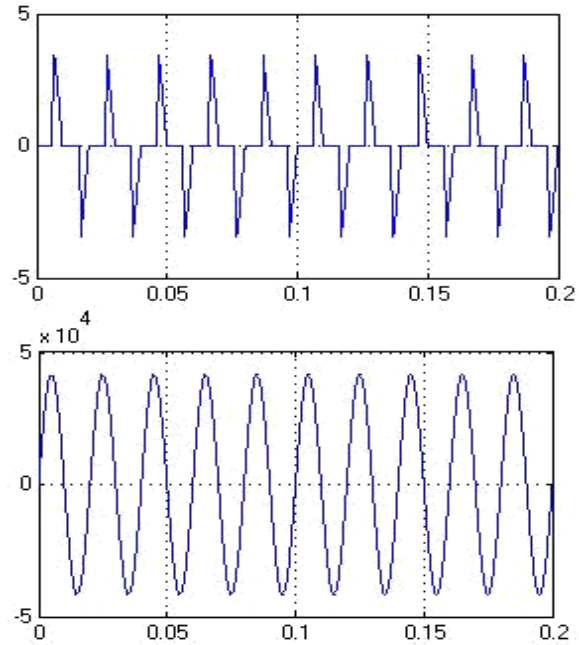


Figure 8(a) Source current without filter. 8(b)Source current with filter (these results are taken keeping firing angle of thyristor bridge rectifier at 120^0)

VI.CONCLUSION

This paper presents an idea about the harmonic reduction by the use of active filters applied to improve the quality of power. The highly developed graphic facilities available in MATLAB were used to conduct all aspects of model implementation and to carry out extensive simulation studies. Here in this project we have designed an active shunt filter using PSO and MATLAB thereby reducing the harmonic distortion limits of the given non- linear load.

PSO (Particle Swarm Optimization), a computational method that optimizes a problem by iteratively trying to improve a candidate solution was used to find the optimum values of the design parameters (inductor and capacitor) of the active shunt filter used in this paper.

Through these values of design components, the THD of the system is considerably reduced to an acceptable limit. This improves the power quality of the supply source and the reason behind this project is hence fulfilled

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