Optimal PI Tuning with GA and PSO for Shunt Active Power Filter

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Abstract: The PI controller plays important role in all engineering controls. The tuning of PI controller is generally done with institutive methods, which are less effective. This paper discusses about the PI controller tuning which affects the results of the total harmonic distortion (THD) of the active power filter. The active power filter is designed for reducing the THD in non-linear load connected power system. It is identified that the variation of proportional constant (Kp) and Integral constant (Ki) affects the THD value. So a problem is formulated to minimize the THD value of the system to find the optimal Kp, Ki parameters. The well-known genetic algorithm (GA) and Particle swarm optimization (PSO) techniques are used to find the optimal value of parameters and minimum THD value. MATLAB Simulink, Sim power system and optimization tool boxes are used.

Keywords: Active Power Filter (APF), Genetic Algorithm (GA), PI tuning and Particle Swarm Optimization (PSO).

Introduction

The power quality is very important nowadays as the need of energy is increasing. The active power filter is used for improving the power quality in the non-linear load connected to the power system. In single phase and three phase system rectifiers or front end converters produces the problem of lower order harmonic injection [1]. Active filter system reduces this problem by injecting the current [2]. There are two types of active power filters, they are shunt and series compensation. The shunt takes care of the current injection and series takes care of voltage injection. Mainly shunt active filters are given priority as it handles the current because current is load dependent [3]. The inverter is used to inject the current to the supply system. The hysteresis control is used for reducing the complexity of PWM generation and current which is to be injected is derived and used as the control technique [4]. A notch based filter is useful in selecting a particular harmonic and removing it. The phase lock loop is eliminated to synchronize with the control part [5].

The Genetic algorithms are also used in the switching of inverters in active power to optimally initialize the switching of inverter, which increases the switching time faster in the initial condition [6]. The control technique used for controlling the pulses is taken from the reference generation of current. Genetic Algorithm is used to produce the reference current, which makes the control faster compared to conventional methods [7]. The hybrid passive filters are introduced to compensate the reactive power as well as harmonics, which has lesser size of inductance [8]. Adaptive filter design is made for synchronization detection and harmonic extraction, which can be used in the Flexible AC Transmission Systems (FACTS) [9]. A robust control strategy with boost converter is presented by the authors in [10] for shunt active filter to improve the performances of the filter.

The upgrade of inverter control strategies also improves the performance of the active filters. A new vector control based hysteresis control is made for improving the transient performance of the system [11]. A non-linear optimal predictive control to improve the stability and robustness of the shunt active filter [12]. The control algorithm is improved to reduce the switching nodes are presented in [13]. The power system is not dealing with three wires (RYB). It also uses four wires (RYBG). A non- linear control strategy is used in [14] to control the power factor with 4-wire system to improve power factor in asymmetrical and non-linear loading condition. A new control strategy with dq-axis is presented in [15] to improve the performance of the shunt active filter. Proportional integral (PI) and Proportional Integral Derivative (PID) based Active power line conditioner is used to improve the power factor is presented in [16, 17]. The analytical analysis of shunt active filter is done for improving the stability and power factor is presented in [19]. The pq theory is meant for identifying the power component. A literature [20] describes that the instantaneous nature of pq is not considered and while considering it gives better results. It is known as Instantaneous reactive power theory. And it is described in analytical method for improving the stability [21]. The unified power quality conditioner is nothing but the combination of shunt and series compensator. It provides the sag and swell compensation of voltage and harmonic compensation in current [22].

Optimization is very important in engineering field to improve the efficiency of the existing system. The PI tuning problem of shunt active filters is not considered in any literature. This problem is formulated and the solution is made with genetic algorithm [18, 23] and Particle swarm optimization[23] are used to find the optimum values of K_p and K_i with minimization of THD.

Problem Definition

The DC link voltage is controlled with PI controller. This PI controller is responsible for total harmonic distortion.

$$I_c = K_p * (V_{dc\ ref} - V_{dc*}) + K_i * \int_0^t (V_{dc\ ref} - V_{dc*})dt \quad (1)$$

Here,
I_c = Compensation current
V_{dc*} = DC measured voltage at DC link
$V_{dc\ ref}$ = DC reference voltage
K_p = Proportional constant
K_i = Integral constant
Objective function is
Minimize $\sum_{i=0}^{n}$ mean (THD) (2)
Subjected to
$P1 \le K_p \le P2$ (3)
$I1 \le K_i \le I2$ (4)
Here,
n = Total number of samples
P1 = lower limit of K_p value
P2 = Upper limit of K_p value
I1 = Lower limit of K_i value
I2 = Upper limit of K_i value

Solution Methods

There are many solution algorithms available in meta-heuristic optimization techniques. GA and PSO algorithms are used due its simplicity.

Genetic Algorithm

Genetic algorithms are based on natural genetics and natural selection. The good properties of parents will produce the child. The natural genetic operations are reproduction, crossover and mutation [23]. Reproduction is used to select the good strings with a probability constant. It is known as probability of reproduction. The equation can be written as

$$P_i = \frac{F_i}{\sum_{j=1}^{n} F_j} \text{ ; i = 1,2,…,n ; j = n+1} \quad (5)$$

$P_i - Mating\ pool$

$F_i - Fitteness\ function$

Crossover is used to create a new strings by exchanging the information among the strings. Mutation is the better fitness values for new generations. The mutation probability changes between 1 and 0. The solution steps are as follows

1. Read the input data like population size, string length, probability of cross over (p_c), probability of mutation (p_m). Populate random kp and ki values (size m).
2. Evaluate the fitness equation (2).
3. Carry out the reproduction process
4. Carry out the crossover operation using the crossover probability p_c.
5. Carry out mutation using probability p_m to find new generation (m).
6. Do the step 2.
7. Check for end of iteration.
8. Stop and show the result.

Particle Swarm Optimization

The PSO algorithm is based on the food searching behavior of the birds or fishes, which is taken as particles. The particle which can get the food faster is made as a mathematical algorithm. The steps of the algorithm is given below,

1. Assume the swarm number is N.
2. Generate the Kp and Ki values. This is called as initial population (X).
3. Evaluate the objective function (2).
4. Find the velocities of the particles. Using the below equation.

$$V_j(i) = V_j(i-1) + c_1 r_1 [P_{best,j} - X_j(i-1)] + c_2 r_2 [G_{best} - X_j(i-1)]; \quad (6)$$

j = 1, 2, ….N.

where,

V – velocity of the particle
i – iteration number
j – particle number
P_{best} – Particle best
G_{best} – Global best
c_1, c_2 – cognitive and social learning rates (chosen as 2)
r_1, r_2 – uniformly distributed random numbers in range 0 and 1.

5. Update the X values using the following equation,

$$X_j(i) = X_j(i-1) + V_j(i); j = 1,2, \ldots, N \quad (7)$$

6. Repeat the step 3 till the end of iteration count.
7. Check for convergence.

Shunt Active Power Filter with Tunning Algorithm

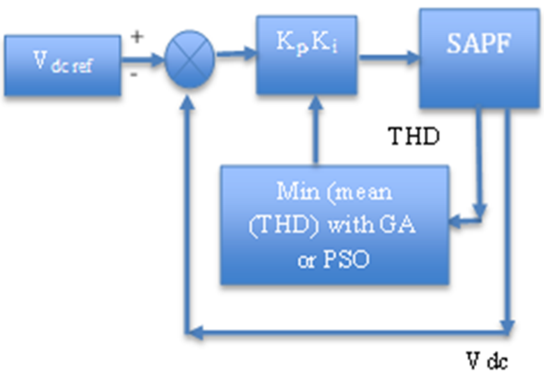

Figure 1. Block diagram of proposed system

The above figure shows the control diagram of the proposed model. The reference dc voltage is given to the comparator. The other side of the comparator is given from the measured V_{dc}. The output of the comparator is given to the PI controller where the K_p and K_i parameters are used. The output of the PI controller is given to the control loop of current in the shunt active power filter (SAPF). The total harmonic distortion (THD) is taken out and given to the objective function. The algorithms generate initial random population of the K_p & K_i parameters. So till the optimum results are reached the algorithm run and produce the optimum value of K_p and K_i value with lesser THD.

Results and Discussions

The simulation is carried out using the parameters given in table 1. The non-linear load taken here is rectifier with RL load. Due to the non-linear load the waveforms are taken as shown in the figure 3.

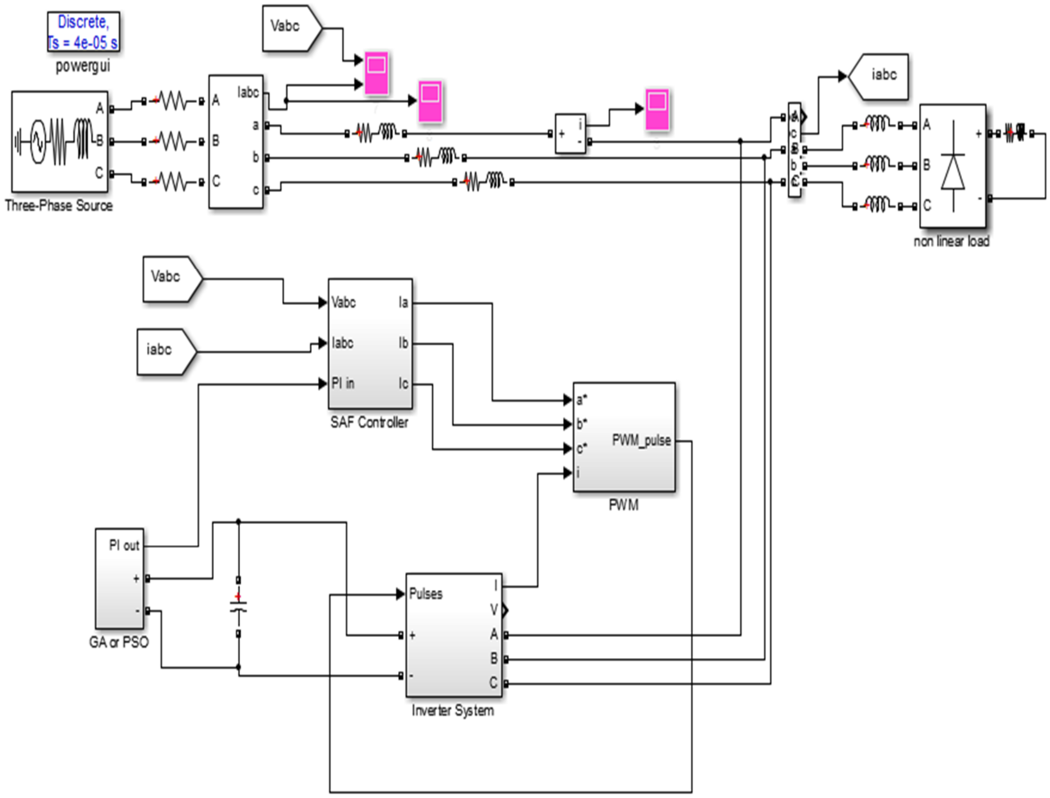

Figure 2. Simulation of the test system

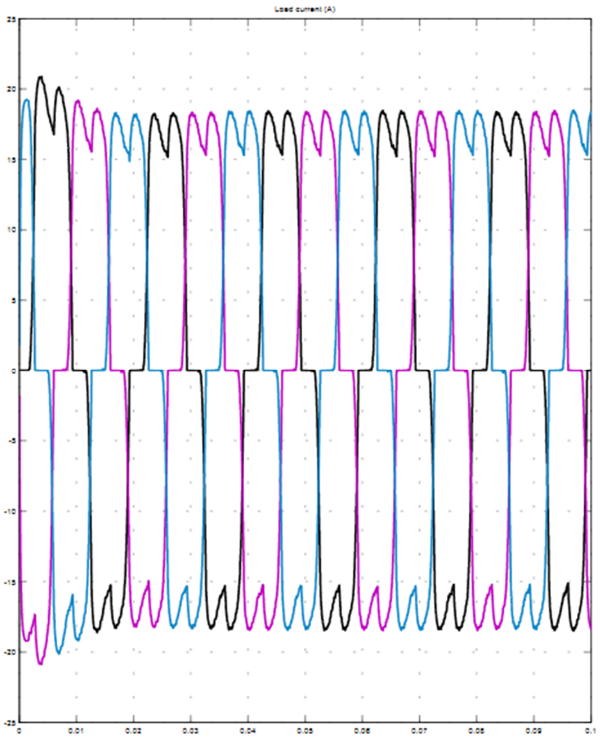

Figure 3. Three phase current waveform before compensation

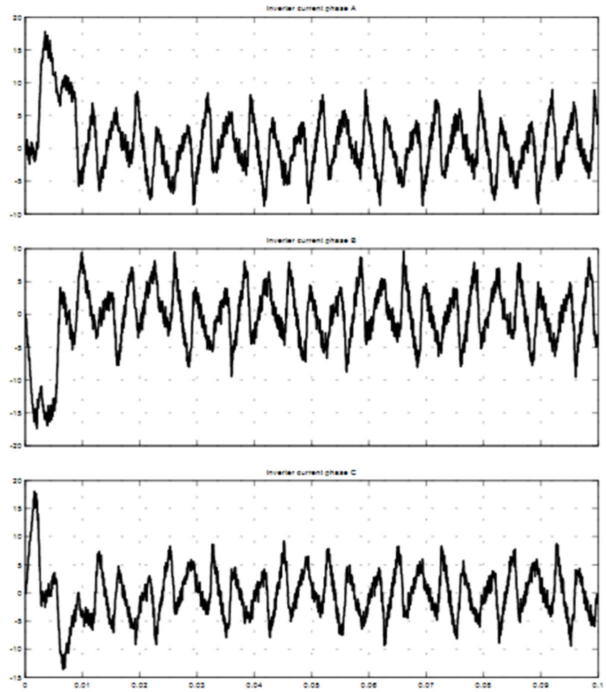

Figure 4. Compensation current produced by the controller

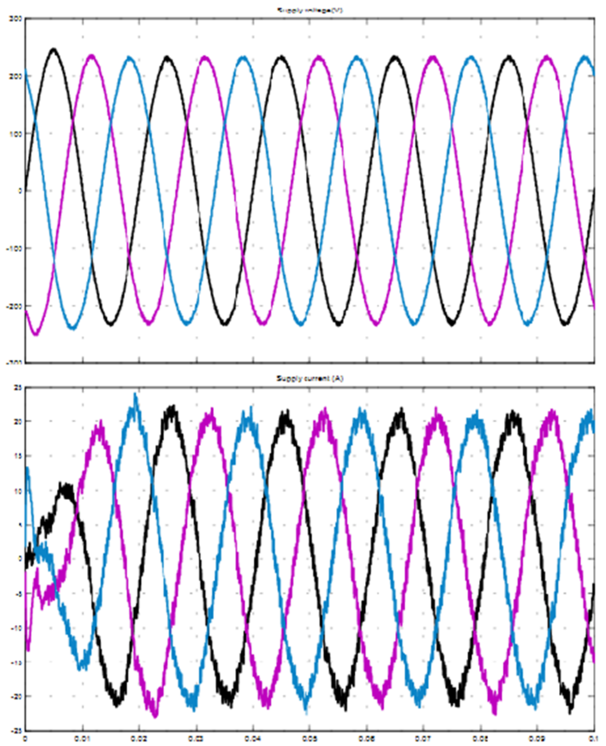

Figure 5. Three phase voltage and current after compensation

The figure 3 shows the current before compensation or load current. Figure 4 shows the compensation current produced by the controller. After injection of the compensation current, the voltage and current waveforms are shown in figure 5.

Table 1. Parameters of SAF

Phase voltage & frequency	310V,50 Hz
Line impedance	R_s =1 Ω, L_s=0.1mH
R-C load	R_L=32Ω,C_L=500µF
R-L load	R_L=26Ω,L_L=10mH
DC bus voltage & capacitance	V_{dc}=500V, C_{dc}= 2000 µF
Shunt active filter ratings	1.81 KVA

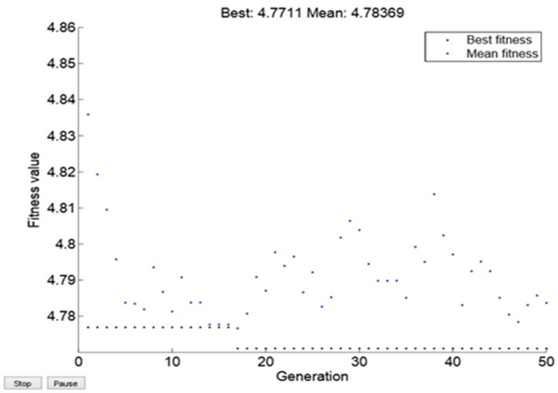

Figure 6. Convergence graph of Genetic Algorithm (GA)

The figure 3 shows the convergence graph of the GA algorithm. The graph shows the THD value nearly 4.77 % which satisfies the IEEE standard for THD.

The parameters used are given below (for both GA and PSO),

Population size : 20

Number of Variables: 2(K_p, K_i)

Range of Variables : 0-0.002

Maximum iteration : 100

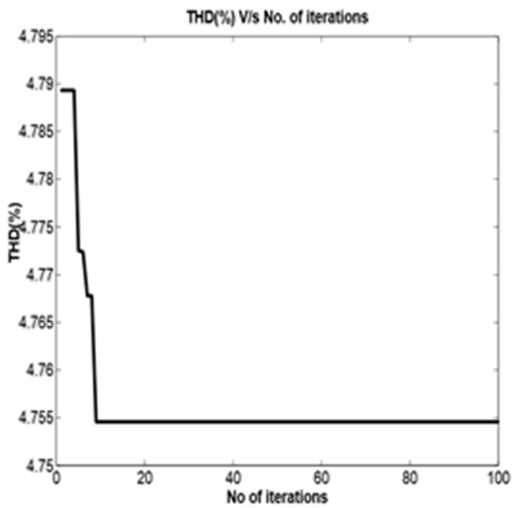

Figure 7. Convergence graph of PSO algorithm

The above figure shows the results of PSO algorithm after solving the objective function. The solution converges in 4.755 % of THD. And it is less compared to the GA method.

Conclusion

The shunt active filter is designed with PI controller and pq theory. The parameter optimization of the shunt active filter is done with two algorithms GA and PSO. The THD value minimization is taken as objective and it is minimized. The optimal values of kp and ki values varies with algorithm and the THD value is also varied. Finally PSO algorithm gives better results compared to GA. The optimal value of kp and ki values are identified.

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