COMPACT GENETIC ALGORITHM FOR DESIGNING LCL FILTER

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ABSTRACT
The attenuation of harmonic of LCL filter is better than that of LC filter; thus, this paper focuses on the design of LCL filter. Compact Genetic Algorithm (cGA) is adopted for designing this filter to solve the problem of difficulty of LCL filter design stage. In this paper, three artificial intelligent techniques, Genetic Algorithm, Compact Genetic Algorithm and Particle Swarm Optimization, are adopted to design the filter. Performance of all techniques are investigated and compared.

KEY WORDS
LCL filter, Compact Genetic Algorithm, Particle Swam Optimization, Genetic Algorithm

1. Introduction
The voltage source converter such as active rectifier has many advantages such as controllable power factor, bidirectional power flow and sinusoidal input current. However, the switch frequency causes high frequency harmonic which cannot be applied to several sensitive loads. Thus, traditional converter adopts L filter to reject the harmonics because of its easy design and applicable in low power applications. However, in high power application, L filter may causes the unstable system. To solve this problem, LCL filter were adopted. In 1995, Lindgren and Svensson designed the grid converter using LCL filter; however, this method is complicated [3]. In 2001, Malinowski proposed a technique to design three phase converters; this method have problem with variable switching frequency and requires a fast microprocessor and A/D converters [4]. In 2005, Liserre designed LCL filter with step by step method; this method performed good performance but difficult to find the filter parameters. In 2006, Liang He proposed the easier method by ignoring the inner resistor. Recently, intelligent algorithm becomes one of the most popular techniques to approximately search the solution in optimization problems. There are many kinds of intelligent algorithms such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and compact Genetic Algorithm (cGA). GA uses the simulation from biology with chromosome to crossover, mutation and reproduction. GA was proposed in many years ago and cGA was presented as the compact version of GA to enhance the speed of convergence of solution of GA. In 1999, Georges introduced cGA method to enhance the ability of GA in terms of fast process and low memory usage [6]. In 1995, Kennedy and Eberhart first introduced PSO method. The method is developed from research on swarm movement such as fish schooling and bird flocking. The features of this method are as follows. Its can calculate faster than GA because it is unnecessary to process selection process and less mechanism [8]. In addition, this method is easy for implementation. For example, Piyapong used this technique to search the answer of H-infinity loop shape technique in control design. In 2009, Wei Sun designed LCL filter with AI method to search the filter parameters but this method is slow computational to find its answer. This paper proposes the design of using cGA to find the filter parameters using three methods and comparing by considering total harmonic distortion and computational time.

2. Model and Design of LCL Filter
The design is separated into two parts those are main circuit and filter design. Followings describe the design in the both parts.

A. Main circuit [1,2]
The main circuit Three-phase voltage source PWM converter with LCL is show in figure1. The parameter : \(e_g, i_g\), \(e_i, i_i\) are the three-phase ac grid voltage and current, \(u, i\) are three-phase ac voltage and current at PWM converter ac side, \(L_g\) is line inductance of grid and \(R_g\) is equivalent series resistors. \(L\) is line inductance at converter ac side and \(R\) is the equivalent series, \(C_i\) is the filter capacitor.

![Figure 1. Three phase voltage source PWM converter with LCL](image)

B. Design LCL filter [1]
The basic design LCL filter have two aspects as follow
1. Good filter harmonic in switch frequency reducing $f$ in (3).

2. The inductor and capacitor should be small as possible because low values of these components can improve the dynamic response and stability of entire system.

The parameter of the design of LCL filter are as follows: rated active power of the system $P_n$, RMS value of the grid voltage $E_n$, angle frequency of grid voltage $\omega_n$ ($f_n=50Hz$), switching frequency of PWM converter $f_{sw}$, DC link voltage of converter $U_{dc}$, and harmonic contents of filter. Define the impedance $Z_b=E_n^2/P_n$ and capacitor $C_b=1/\omega_n Z_b$.

**Simplified method (Conventional technique) [1]**

1. Define $L_g$ by using the following equation and the specified peak current, $i_{rpm}$.

\[
L_g = \frac{E_n}{2\sqrt{6}i_{rpm}f_{sw}} \tag{1}
\]

2. Choose $L$ by $L_g=2L$.

3. Choose $C_f$ by $L$ and $L_g$

\[
f_{res} = \frac{1}{2\pi} \sqrt{\frac{L+L_g}{LL_gC_f}} \Rightarrow C_f = \frac{L+L_g}{LL_g(2\pi f_{res})^2}
\]

\[
10f_n \leq f_{res} \leq 0.5f_{sw}
\]

\[
C_f \leq 15\% C_b \tag{2}
\]

**Constraints**

1. Value of capacitor of LCL filter will produce reactive power for guarantee have high power factor. The constraint value capacitor need $C_f < 5\% C_b$.

2. Consider the stability of system and power loss in switch device. The total inductance is lower than 0.1 pu that is $L+L_g \leq 0.1 L_b$.

3. To avoid the resonance at lower order op high order. The resonance frequency should be $10f_n \leq f_{res} \leq 0.5f_{sw}$.

**3. Intelligent Algorithms**

In traditional design as described in Section 2, it is not easy to fulfill the restriction by trail and error method. In this paper, the brief details of intelligent optimization algorithm to search the solution to meet the restricted points such as Genetic Algorithm (GA), particle swarm optimization (PSO) and compact Genetic Algorithm (cGA) are presented.

**A. Genetic Algorithm [7]**

This parameters needed to be specified in this technique are as follows: generation, which is the cycle for GA method, Population size, which is the number of generations, Fitness function, which is the function indicated how suitable of candidate of solution. Probability of mutation, crossover and reproduction. The fitness function of this problem is shown in (3).

\[
f = \frac{i_{g}(h_{sw})}{i(h_{sw})} = \frac{z^2}{L_C} \left| \omega^2_{res} - \omega^2_{sw} \right| \tag{3}
\]

The process of GA is as follows:

1. Define the GA parameters: boundary of solution, population size, maximum generation, fitness function in (3), probability of crossover, mutation and re-production.

2. Randomly choose the value of chromosome in 1st generation

3. Calculate the fitness function of each chromosome

4. Randomly select the operator and find the new chromosome on next generation. Examples of the description of GA operations shown in the followings:

4.1 Cross over, this operator selects the next generation by random selection the position of crossover point and making swap between two chromosomes.

1st generation: 1st chromosome 10001110

1st generation: 2nd chromosome 11101010

2nd generation

1st generation: 1st chromosome 10001010

1st generation: 2nd chromosome 11101110

2nd generation

1st generation: 1st chromosome 10001010

1st generation: 2nd chromosome 11101110

4.2 Reproduction, this technique just copies the chromosome.

1st generation: chromosome 10001110

2nd generation

1st generation: chromosome 10001110

2nd generation: chromosome 10001110

4.3 Mutation, this method randomly select the point to be mutated and then generate the 2nd generation by changing the value of bit at the mutated point.

1st generation: chromosome 10001110

2nd generation

1st generation: chromosome 10001110

2nd generation: chromosome 10101110
5 Get 2nd population

6. If the stopping criteria are not met, go back to step 3.

B. Particle Swarm Optimization [8,9]

This technique is based on the concept of simulating the movement of swarm of birds, which contact to exchange information for the best location. The process will similar to GA except the next population is calculated by performing the next population by the swarm movement equation.

C. Compact Genetic algorithm [6]

This technique is also similar to GA. The technique uses only the crossover operator to update the chromosome. cGA defines a constant size of $1/n$ for being the population size. The random with biased probability of the bit is processed for generating next generation. With the bound with $n+1 \ (0,1/n,2/n,...,n/n)$, cGA can store with $\log_2(n+1)$ bits. cGA can deals with low memory application and large search space size. Followings show the concept of cGA.

1. Define parameter: bounds, population size ($n$), maximum generation, fitness function and probability of crossover

2. Random the chromosome in 1st generation within specified bound

3. Randomly select two chromosomes with highest and lowest fitness function values called them as winner and loser, respectively.

4. Generate the next generation by modifying the bit by randomly check the winner or loser by updating the bit probability by adding or subtracting $1/n$.

5. When the probability vector is balanced or no updating, it means that the final solution achieved.

4. Simulation Results

This paper adopts MATLAB/SIMULINK to simulate the system shown in Fig. 2. The parameters of this circuit are: $V_{rms} = 60$ volts, switch frequency = 4 kHz, load $R_{dc} = 100$ ohms.

![Control system of VSC with LCL filter](image)

To compare three techniques, calculate the solution with ten times and finding the mean values of THDi. Lower THDi means better solution. Boundary of solution is set to follows: $L : 0.1 \text{ mH to 5 H and } C : 4 \mu F$ to 50 $\mu F$ and resonance frequency is 500 Hz to 5000 Hz. The results of GA, PSO and cGA are shown in Tables 1, 2 and 3, respectively.

Parameters in GA are as follows: population size = 100, crossover = 0.7, mutation = 0.1, and maximum generation = 100.

Table 1 Test results of cGA design

<table>
<thead>
<tr>
<th>Generation</th>
<th>L (H)</th>
<th>C (\mu F)</th>
<th>F (Hz)</th>
<th>%THDi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0004</td>
<td>183.95</td>
<td>713.91</td>
<td>4.01</td>
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<tr>
<td>2</td>
<td>0.0001</td>
<td>538.49</td>
<td>834.53</td>
<td>3.33</td>
</tr>
<tr>
<td>3</td>
<td>0.0047</td>
<td>38.33</td>
<td>1433.4</td>
<td>5.28</td>
</tr>
<tr>
<td>4</td>
<td>0.0007</td>
<td>96.71</td>
<td>744.27</td>
<td>4.26</td>
</tr>
<tr>
<td>5</td>
<td>0.0026</td>
<td>31.86</td>
<td>672.75</td>
<td>4.07</td>
</tr>
<tr>
<td>6</td>
<td>0.0003</td>
<td>64.654</td>
<td>923.6</td>
<td>3.62</td>
</tr>
<tr>
<td>7</td>
<td>0.0005</td>
<td>61.03</td>
<td>1567.36</td>
<td>5.20</td>
</tr>
<tr>
<td>8</td>
<td>0.0004</td>
<td>150.28</td>
<td>836.15</td>
<td>5.24</td>
</tr>
<tr>
<td>9</td>
<td>0.0008</td>
<td>110.65</td>
<td>905.24</td>
<td>3.52</td>
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<tr>
<td>10</td>
<td>0.0003</td>
<td>80.946</td>
<td>1045.62</td>
<td>3.83</td>
</tr>
</tbody>
</table>

The calculated mean of THDi is 4.23% and the computational time is about 21 seconds. Fig. 3 shows the result from the best chromosome.

Particle Swarm Optimization

Parameters in PSO are as follows: population size = 100, minimum velocity is 0, maximum velocity is 4, acceleration constants is 2.1, inertia weight is set to 0.6
and 0.9, and max iteration is 100. The results of average THDi is 4.38% and the computational time is about 18 seconds. Fig. 4 shows the results of time domain by the best solution obtained from the 10 iterations running of the PSO.

Figure 3. The results of PSO (a) convergence curve (b) time domain of the best fitness and (c) spectrum of the current. by GA technique

Figure 4. The results of the best particle from the PSO, (a) grid current before and after passing the LCL filter (b) Spectrum of grid current

Compact genetic algorithm

In this technique the parameter are set as: population size = 100, crossover = 0.7, mutation = 0.1 and maximum generation = 100. The results are shown in Table 2. Calculated mean THDi is 4.43% and the usage time for simulation is 0.5 second. Fig. 5 shows the results of best chromosome evolved by cGA.
Figure 5. The results of the best chromosome evolved by cGA. (a) convergence curve, (b) (above) grid current of LCL filter, (below) converter current grid and (c) spectrum of grid current

<table>
<thead>
<tr>
<th>Table 2 Test results of cGA design</th>
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<tbody>
<tr>
<td><strong>Generation</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
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<tr>
<td>3</td>
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<tr>
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<tr>
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<td>10</td>
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</table>

As seen in the simulation results on rectifier system with LCL filter, the current of harmonic is decreased by LCL filter to be the values as 4.23%, 4.42% and 4.38% by the LCL filter designed by the techniques GA, PSO and cGA, respectively. This values show the quality enough for using complied with with the IEEE std. 519-1992. Table 3 shows the calculation time for all techniques mentioned above.

<table>
<thead>
<tr>
<th>Table 3 Calculation time of 3 techniques</th>
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<tr>
<td></td>
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<tr>
<td><strong>Time (s)</strong></td>
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5. Conclusion

The design LCL filter with cGA is proposed to be an alternative method for designing the filter. When simulating by three intelligent techniques, we found that the fitness function or THDi of the proposed technique is almost the same as that of the two intelligent techniques. The simulation results of THDi and spectrum of grid current show that the proposed technique is applicable. In addition, the computational time of the proposed technique is lesser than that of the other techniques.

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References