Harmonic suppression of AC-DC Buck converter based on genetic algorithm PID Control

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ABSTRACT: *The switch on of AC-DC Buck converter brings harmonic waves to the grid, and causes the decline of power factor, affects the grid power quality. This paper comparing with the current harmonic suppression methods, considering to employs PID control, as the manual regulation of parameters, it is hard to achieve good controlling effect.It proposes an inverter harmonic suppression method based on genetic algorithm PID control. It gives the AC-DC Buck converter circuit structure and controlling model, analyzes the operating principle and conducts simulation verification. The simulated results show that this method can suppress harmonic effectively and improve the power factor, which has certain utility value in practical application.*

Keywords: Genetic Algorithm PID Control, AC-DC Buck Converter, Harmonic Suppression

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1. Introduction

In the application occasions of switch power supply, uninterruptible power supply and AC-DC-AC frequency converter, presently most of them are gotten from the capacitor filtering of uncontrollable rectification circuit and then provide DC power for the inverter in the latter stage. However, the switch on of uncontrollable rectification circuit would bring harmonic wave and cause the decline of power factor, which would severely affect the grid power quality. In order to solve these problems, In literature, A harmonic elimination technique based on PWM is proposed for single-switch three-phase AC-DC Buck converter. Through simple feed forward operation, it can eliminate all low order harmonic voltage contained in input stage. Conventional larger smooth capacitor is dispensed with, and the ripple and harmonic current of AC supply is reduced greatly. The adaptation for supply unbalance and harmonic distortion is fulfilled as well.; Literature(Jinghui and Rui,2012; Zhang,2007)resorts to the method of utilizing active power factor corrector; both methods have obtained good effect. But these methodsare only part of the solution to the problem of harmonic suppression and power factor improvement, are unsatisfactory. This paper adopts the method based on genetic algorithm PID controlling to do some research on harmonic suppression and improving power factor.

2 . Genetic Algorithm Principle

Genetic algorithm is a random search algorithm which is based on biology natural selection and genetic mechanism and it starts searching from the initial solution of a group of random generated “population”. Each individual in this population is a solution to the question and is called chromosome. Chromosome is a string of signs such as a binary system character string. These chromosomes evolve continuously in the follow-up iteration, which is named heredity. In each generation, “*fitness*” is used to measure the quality of the chromosome. The generated younger chromosome is called offspring. Offspring is formed by crossover or mutation calculating the older chromosome.

In the forming process of the younger generation, according to the size of the fitness to choose part of the offspring and to weed out the others. Thus the size of the population is a constant. Those chromosomes whose fitness is higher are more likely to be chosen. After several generations like this, the algorithm can collect the best chromosome and it is probably the optimal or suboptimum solution to the problem. It includes the following five steps: coding, generation of the initial colony, evaluation and test of adaptability value, selection, crossover, and mutation.

3. Principle Analysis of Genetic Algorithm PID Controlled Harmonic Supperssion Circuit

genetic algorithm PID controlling harmonic suppression circuit refers to a high-frequency rectification circuit, in which we integrate active devices controlled by genetic algorithm PID to the traditional uncontrollable rectification circuit to make the AC side current become sine in certain degree, consequently to reduce the nonlinearity of the device, improve power factor and decrease harmonics.

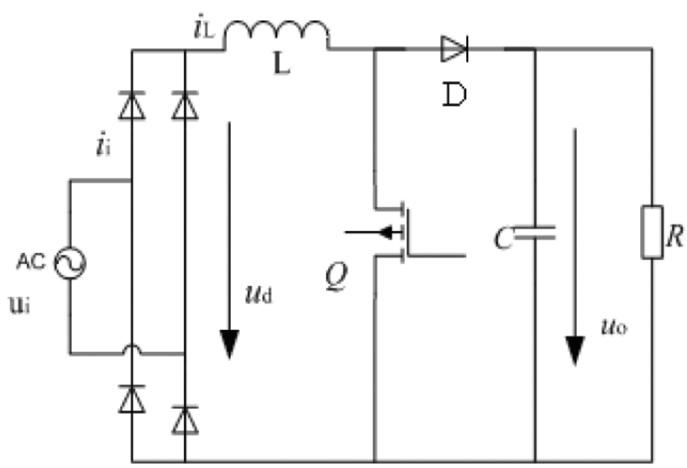

Figure 1. Schematic diagram of AC-DC Buck converter

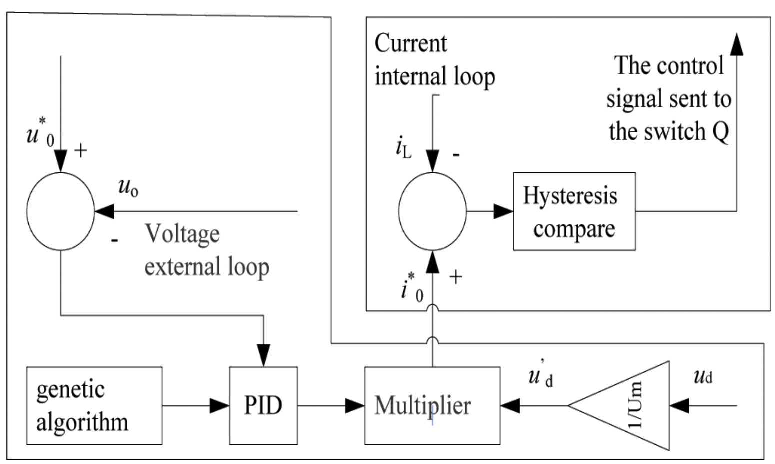

Figure 2. Internal structure chart of harmonic suppression circuit with genetic algorithm PID controlling

The concrete genetic algorithm PID controlled harmonic suppression circuit is to add a DC-DC power conversion circuit (Boost circuit as usual) between single-phase bridge uncontrollable rectifier and load resistance. Through proper controlling on-off of the switch tube in the Boost circuit, we can correct the input current of the rectifier to the sine wave which is synchronous to the grid voltage, then cancel the harmonics and reactive current, which will improve the grid power factor to approach 1. The schematic diagram of this circuit is shown in Figure 1. Q is switch tube; L is inductance; C is output capacitance and R is load.

Suppose the switching frequency is high enough, in order to ensure the current continuous of inductance L the output capacitance C should be big enough and the output voltage u_o can be regarded as the constant DC voltage. Grid voltage u_i is of ideal sine, $u_i=U_m\sin\omega t$. Then the output voltage u_d of uncontrollable bridge is half-sinusoid $u_d = |u_i| = |U_m\sin\omega t|$.

When the switch tube *Q* is on, u_d charges for inductance and inductance current i_L increases, then capacitance *C* discharges to load. When *Q* is off and the diode *D* is on, the two ends voltage u_L of inductance reverse; u_d and u_L charge for capacitance; then inductance current i_L decreases and meets the following equation:

$$L\frac{di_L}{dt}=u_L=\begin{cases} U_m\,|\sin\omega t\,|, t_k<t<t_k+t_{on} \\ U_m\,|\sin\omega t\,|-u_o, t_k+t_{on}<t<t_k+T_s \end{cases}$$

By controlling the on and off of Q, which means regulate the duty ratio, we can control inductance current i_L. if i_L can be adjusted to be approximately half-sinusoid current and have the same phase with u_d, then the rectification bridge AC side current i_i is similar to sine current too and has the same phase with grid voltage u_i. As a result, the purpose of harmonic suppression and power factor correction can be attained. In this paper, we realize such a purpose by resorting to introduce a genetic algorithm PID controlled double closed loop controller with a voltage outer ring and a current inner ring. This controller can meet two requirements. The first one is to realize the regulation on output DC voltage u_o and get the set value. The second one is to guarantee the grid side current to be sine and power factor to be 1, which means to make the inductance current i_L and u_d similar in wave form in the case of stable output voltage u_o. The principle circuit structure is shown in Figure 2.

The voltage outer ring is mainly used for getting the inductance current instruction value i^*_L which can used to control targets. The D-value of the set output voltage u^*_o minus the measured actual output voltage u_o, outputs the amplitude command i^*_L of inductance current by passing through PID controller. After the measured rectification bridge exit voltage u_d dividing its amplitude value U_m, we can get u'_d which is used for representing the value of waveform u_d. u' is the half-sinusoid whose amplitude value is 1, and has the same phase with u_d. If we multiple i^*_L with u'_d, then we can get the inductance current instruction value i^*_L. i^*_L is the half-sinusoid current and has the same phase with u_d, and its amplitude value can control the value of DC voltage u_o.

The current inner ring is mainly used for making the actual inductance current i_L track instruction value i^*_L through controlling the on and off of the switch tube Q(Liu et al, 2010;Zuo et al, 2007). We utilize the method of hysteresis current controlling there. According to the formula of inductance current, when Q is on, the inductance current would increase; when the Q is off, the inductance current would decrease. Minus i_L from i^*_L, if the D-value Δi_L is greater than the prescribed upper limit Δi_{Lmax}, then Q is made on to increase i_L; if the D-value Δi_L is less than the prescribed upper limit Δi_{Lmin} ($\Delta i_{Lmin}<0$), then Q is made off to decrease i_L. Through hysteresis regulation, we can ensure the actual inductance current i_L fluctuates around the instruction value i^*_L. The fluctuation range is related to the hysteresis width, which means that it relates to the set Δi_{Lmax} and Δi_{Lmin}.

When PID control of the outer voltage ring, the performance of PID controller is determined by the reasonability of the three parameters *kp*, *ki* and *kd*. At present, the PID controller parameters are mainly manual regulated, which is not only time-consuming but also cannot guarantee the best performance, In order to make the controlling of the system reach optimum, the design of employing genetic algorithm is used to optimize PID controller parameters. In Figure.2, it is the procedure chart of a genetic algorithm optimizing PID controller parameters. After adopting genetic algorithm to optimizing PID controller parameters, then the optimized parameters will be brought to the PID controller. Presume the parameter setting of genetic algorithm is: the sample amount is Size = 25; the terminal evolution algebra is 180; the crossover probability is 0.6; the mutation probability is 0.001-[1:1:size]*0.001/size. after 180 generations genetic algorithm optimization of the 3 parameters, The evolution process of genetic algorithm cost function is as shown in Figure. 3.

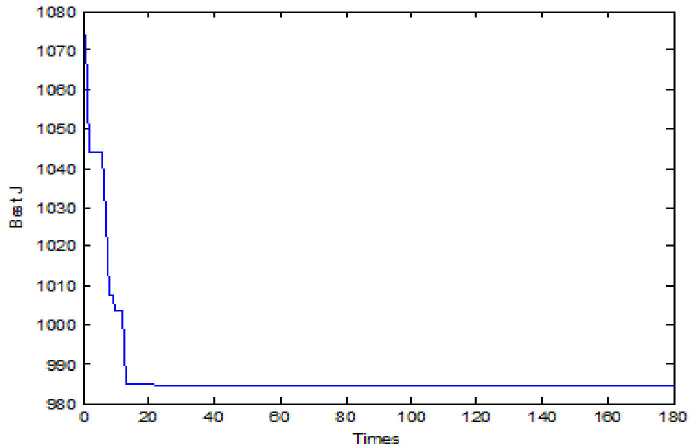

Figure 3. Evolution process chart of genetic algorithm cost function

4. Simulation Modeling

Figure 4 is the uncontrollable rectification circuit simulation diagrammatical figure when there is no genetic algorithm PID controlled harmonic suppression circuit. Figure 5 is the simulation diagrammatical figure of genetic algorithm PID controlled harmonic suppression circuit when adopts Boost circuit. The Mosfet and Diode modules in this figure 4 and figure 5, which come from Sim Power Systems/Power Electronics module base, are switch tube Q and diode D separately corresponding to figure 1. The DC voltage instruction u^{*}_{o} is 400V, which is realized by adopting the Costant in Simulink/Sources module base. PID Controller is the module of PID controlling, whose parameters are k_p= 0.420、k_i = 4.90、k_d = 0. Different parameters have different effects on harmonic suppression. “*Relay*” is the hysteresis comparator which uses the “*Relay*” module in Simulink/ Disconinuities module base and the hysteresis width is set as [-1,1] . “*AC voltage source*” is AC power supply. Suppose the effective value of the input voltage is 220V and the frequency is 50 Hz. “*Voltage Measurement*” is the voltage measuring module. “*Current Measurement*” is the current measuring module. “*Fourier*” is the Fourier transforming module. “*Discrete Active & Reactive Power*” is the active power and reactive power measuring module. “*Display*” is the display module and “*Powergui*” is the graphical user interface. Suppose the input DC voltage instruction u^{*}_{0} is 400V, the inductance L = 2mH, the capacitance C = 4700ìF and the load resistance R = 9Ω; in the diode rectification bridge, set R_s=1e5Ω、C_s = inf、R_{on}= 1e-3 Ω、L_{on}= 0、V_f=0; switch Q takes MOSFET, setting R_{on}= 0.001Ω、L_{on}= 0、V_f = 0、R_d= 0.01Ω、Ic = 0、Rs = 1e5Ω、Cs = inf; as for the diode parameters in Boost circuit, we set R_{on}= 0.001Ω、L_{on}=0、V_f = 0.8V、Ic = 0、Rs = 500Ω、Cs = 250e-9F.

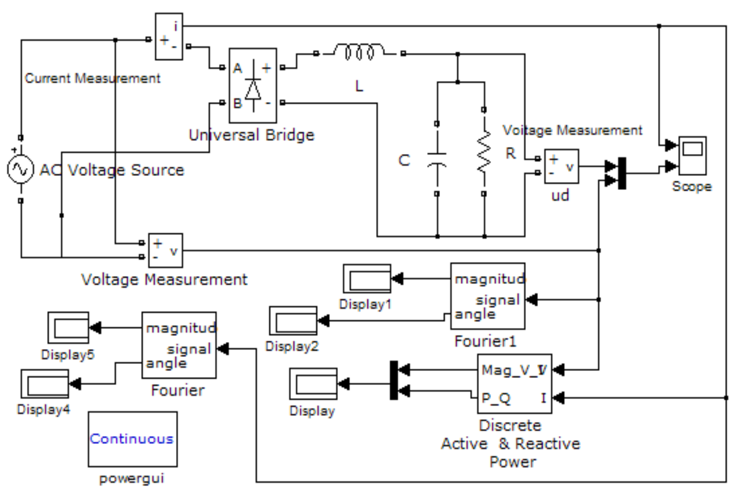

Figure 4. Simulation diagrammatical figure of uncontrollable rectification circuit

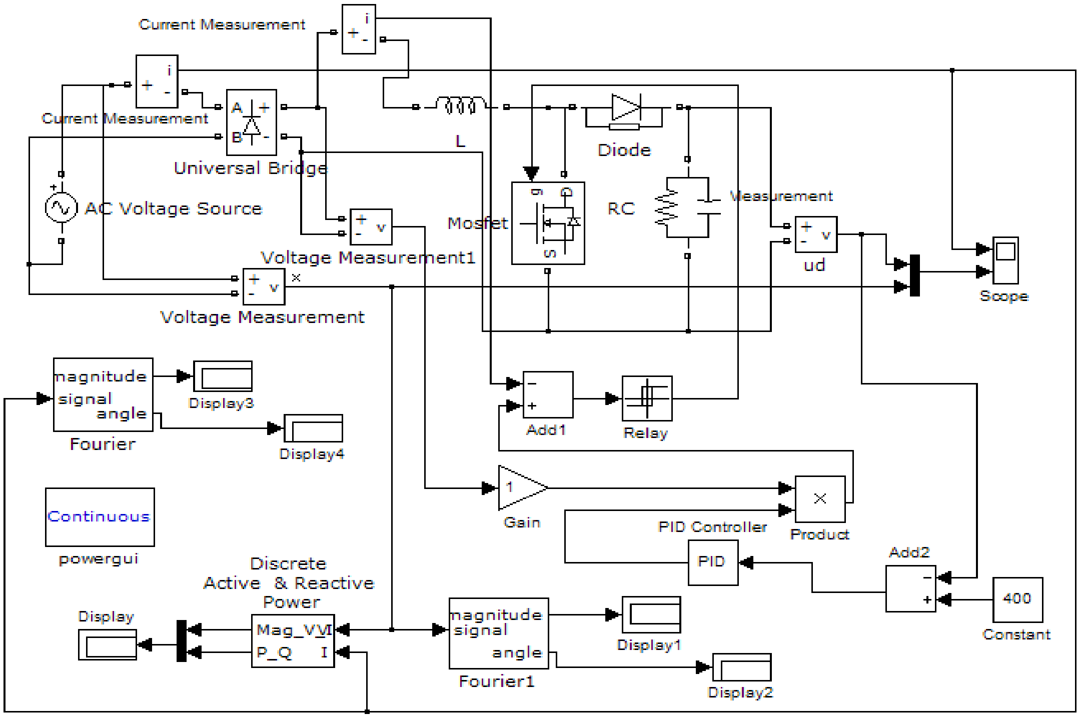

Figure 5. Simulation diagrammatical figure of PID controlled harmonic suppression circuit

5. Simulation Results Analysis

Utilizing Powergui to set the simulation as constant module, and set the simulation parameter Start time as 0s, Stop time as 0.2s and the other as default parameters. Click the simulation shortcut key icon to start the simulation procedure.

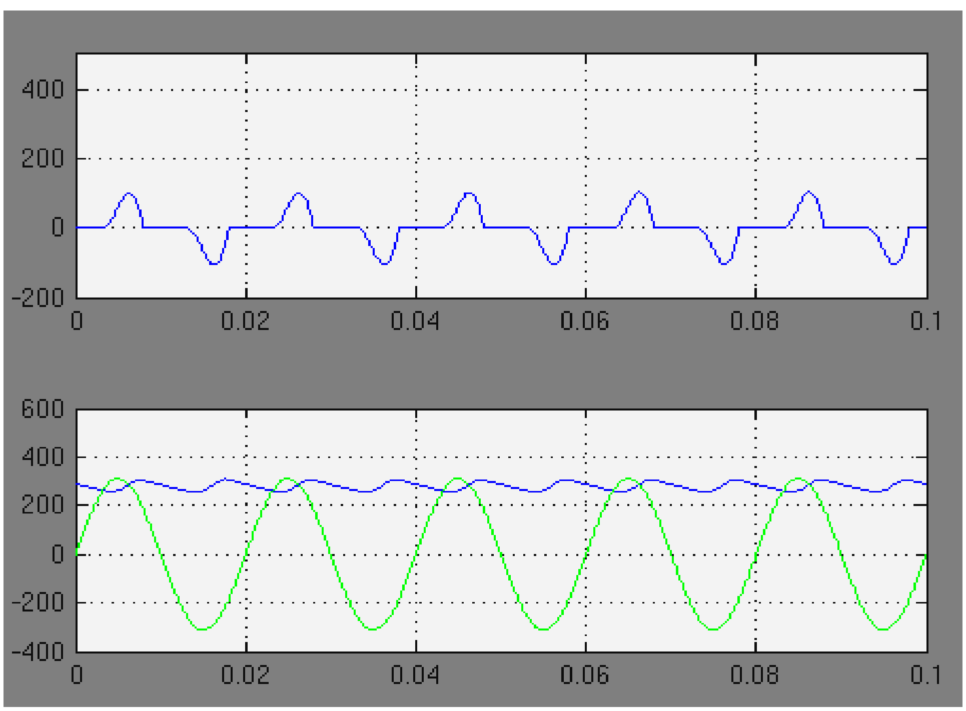

Figure 6. Waveform of u_i, i_i and u_o

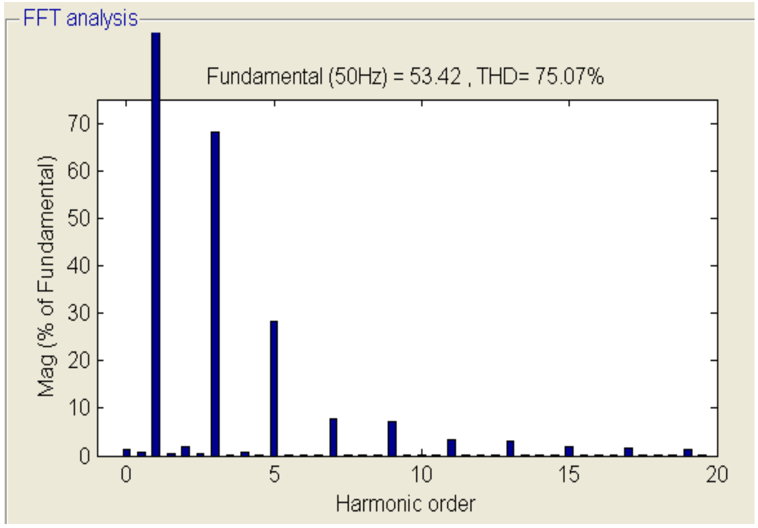

Figure 7. FFT analysis result diagram

Figure 6 is the waveform of current voltage when no harmonic suppression circuit is added here. The above curve is the waveform of AC side current while the below one is the waveforms of rectified DC side current and AC side voltage. When it is being FFT analyzed we can get its THD is 75.07%, which can be seen from Figure 7. From figure 4 we can see that the phase angle of the current is 13.59 and that of voltage is 25.69. There is some D-value of the phase. The active power is 9161.70 and the reactive power is 2085.42. After calculation, we can get the power factor of 0.9751. Figure 8 is the waveform of AC side u_i and i_i after adding harmonic suppression circuit and the waveform of DC side after rectification. Through FFT analysis of it, we get its THD of 4.94%, which can be seen from Figure 9 and it's obviously lower than that in Figure 7, thereby to reach the purpose of harmonic suppression. From Figure 8 we can see that the current and voltage basically have the same phase. Additionally, we can judge whether the current and voltage are of the same phase from observing the phase angle of Fourier module (as shown in Figure 5). From Figure 5 we can see that the current phase angle is 27.73, the voltage phase angle is 25.69. Both are mainly similar. Figure 5 also shows that the active power is 13045.67 and the reactive power is -471.37. After calculation we can get the power factor of 0.9993, which means that the power factor is approximately 1 and the power factor improves greatly than that of Figure 4.

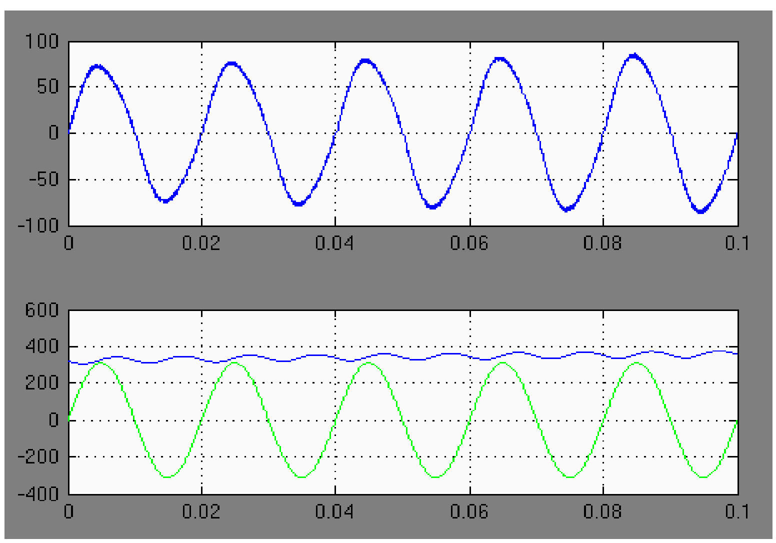

Figure 8. Waveform of u_i, i_ih and u_o

If we change the hysteresis width into [-0.5, 0.5] and re-simulate Figure 5, we can find that its THD is 2.31%. The THD value becomes smaller. Thus it is clear that when the hysteresis width is changed into [-0.5,0.5], the current side harmonic wave is smaller, meanwhile the power factor increases to nearly 1. For current grid, it can further decrease the disturbance.

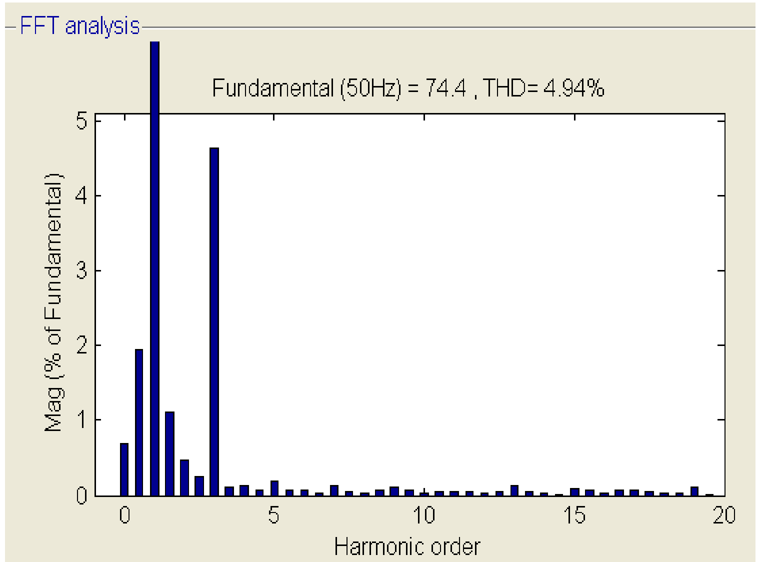

Figure 9. Diagram of FFT analyzed results

6. Conclusions

When using switch power supply, AC-DC-AC frequency converter and UPS, there is an AC-DC conversion process. But when the AC-DC Buck converter is switched onto the grid, it would bring grid harmonic wave and decrease the power factor. In order to reduce harmonic wave, increase power factor, and improve power quality, we can switch on a genetic algorithm PID controlled harmonic suppression circuit. Through simulation, we can get sufficient evidences. Moreover, the smaller the hysteresis is, the higher the power factors are and the greater the harmonic wave decreases, which is helpful for researchers in improving grid power quality when switching on AC-DC Buck converter

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