Fuzzy Self-tuning PID Control Method Based on Multi Intelligent Particle Swarm Optimization Algorithm

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Abstract **— DC speed regulating system is a complex control system with degradation and nonlinearities, and difficult to establish a precise mathematical model. The traditional control methods depend on accurate mathematical modelling of the controlled object, and it is not possible to dynamically adapt to the DC speed control system to obtain high control precision. An improved hybrid genetic algorithm for PID is proposed to deal with the big randomness of slow iteration process, weak local searching capacity and other problems in harmonic detection simulation with genetic algorithms. The method i) improves the complexity of the genetic algorithm, ii) enhances its calculation efficiency with strong local convergence capacity of quasi-Newton algorithm, and iii) solves such problems as insufficiently precise harmonic balance simulation and slow operation in practical condition. Our simulation results show that the algorithm has such advantages of: i) less number of iterations, ii) fast convergence rate, iii) high convergence efficiency, iv) high solution precision, and v) can significantly improve calculation efficiency for solving harmonic detection equations. In addition, the simulation and measured curves fit well to explain: i) insufficiently precise simulation results, ii) slow operation and other problems, and has promising application prospects.**

Keywords - PID; intelligent particle swarm ; Anti gauss disturbance; control system; speed adaptive

I. INTRODUCTION

Domestic and foreign scholars on DC speed regulating control system has conducted the research and the exploration, the other method is introduced into the procedure of adjusting the PID parameters, the combination of fuzzy control and PID control method is proposed. The method can according to the DC speed control system output changes and dynamic adjustment of parameters and improve the control accuracy of the system [1]. However, this method relies on a large degree of proportion, integral, differential 3 parameters of the initial value of the setting, once the 3 parameters are set incorrectly, the system control precision is very low, the robustness is poor [2-4]. And some scholars put forward the combination of neural network and PID DC speed control system, because the neural network has strong nonlinear mapping ability and adaptive ability and timing variability and uncertainty of the system has a good real-time performance and robustness, so it is scholars put forward the combination of neural network and PID double closed-loop DC speed control system, the simulation results show that, this method better overcome the defects existing in the traditional PID, the stability and control accuracy of the control system were improved, obtain good control effect [5]. However in practical application, neural network with insurmountable defects, such as the complexity of the network structure and initial parameters value is difficult to determine, overfitting and local optimal value and so on, the method exists some limitations [6]. SVM (support vector machine, SVM) is developed in recent years, the intelligent learning algorithm, the better way to overcome the neural network fitting and local advantages and disadvantages, and has the advantages of simple structure and fast learning speed, DC adjusting control system research provides a new tool for [7].

II. PID FUZZY CONTROL THEORY

The traditional PID controller of DC speed control system in the process, because of the DC speed control system with degeneration and randomness and uncertainty, is unable to establish the precise DC speed regulation system of the mathematical model, and the control effect of traditional PID control is dependent on accurate mathematical model of controlled object, so traditional PID to adapt to dynamic DC speed control system, meanwhile, SVM is nonlinear control ability, do not need to establish the precise DC speed regulation system of the mathematical model can be on the accurate approximation. Therefore, this study will SVM and traditional PID combined control DC speed regulating system. Harmonic balance method is both applicable to strong or weak nonlinear circuits. It requires re-permutation and combination for elements constituting nonlinear circuit and divides them to linear network and nonlinear network. Harmonic balance equation is established through equal current at the port and appropriate method is adopted to solve the equation.

Basic principles of harmonic balance are: to divide the circuit to nonlinear network and linear network, as shown in Fig. 1. Wherein, nonlinear network only contains nonlinear element and linear network includes all linear elements, source terminal impedance, load impedance, DC bias and excitation in circuits.

Equivalent model for small signal of PID fuzzy control algorithm is shown in Fig. 2. Wherein, elements beyond virtual frame are parasitic element irrelevant to bias and those in the virtual frame are intrinsic element relevant to bias. Equivalent model for small signal and parameter extraction technology are the basis to understand physical mechanism of devices and establish nonlinear equivalent model. Establishment of precise equivalent model for small signal is of great importance to solve equivalent model for large signal. Hence, the Thesis imitates method of literature [13] and adopts parameter of non-intrinsic element as independent variable for parameter function of intrinsic element to solve parameters of equivalent model for small signal. With non-intrinsic element of PID fuzzy control algorithm at zero bias as initial value, the value of intrinsic element is obtained through optimization. The method can precisely describe actual working condition of PID fuzzy control algorithm, with fast convergence rate and high calculation efficiency to satisfy need of analog simulation.

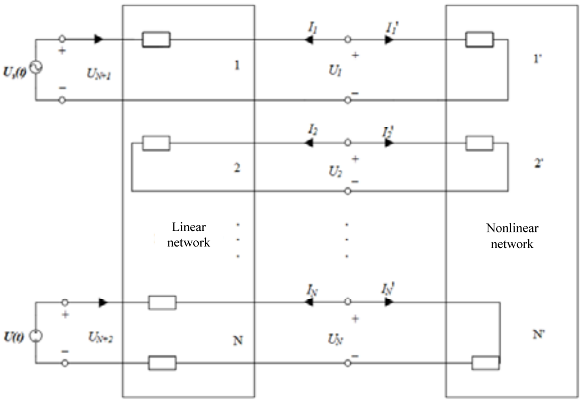

Figure 1. Schematic diagram of harmonic detection

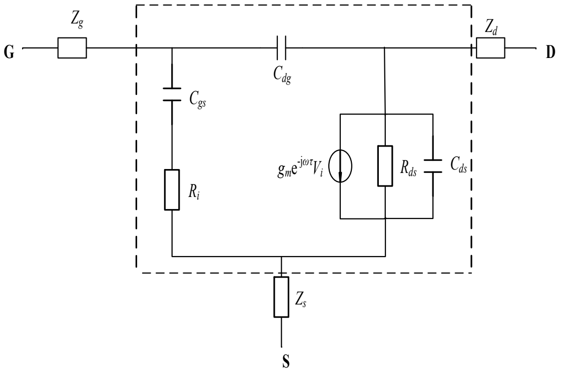

Figure 2. Equivalent model for small signal of PID fuzzy control algorithm

Equivalent model for large signal of PID fuzzy control algorithm is shown in Fig. 3. Nonlinear elements in the figure are I_{ds} , I_{gs} , I_{ds} ; other parameters have been solved in the equivalent model for small signal. The expression of nonlinear element can be solved and parameters of equivalent circuit for large signal can be extracted through measurement of volt-ampere characteristic curve under DC status and curve fitting by MATLAB software according to selected empirical formula.

The empirical formula of nonlinear current is:

$$I_{gs} = I_{g0}\left(e^{\alpha_f V_g} - 1\right) \tag{1}$$

$$I_{dg} = I_{b0}\left(e^{\alpha_r V_{dg}} - 1\right) \tag{2}$$

$$I_{ds} = \frac{\beta\left(V_g - V_T\right)^2}{1 + b\left(V_g - V_T\right)}\left(1 + \lambda V_d\right)\tanh\left(\alpha V_d\right) \tag{3}$$

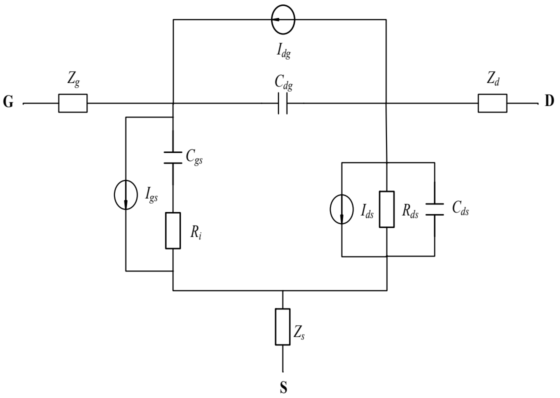

Figure 3. Equivalent model for large signal of PID fuzzy control algorithm

Equivalent model for large signal of PID fuzzy control algorithm is decomposed into linear network and nonlinear network, as shown in Fig. 4. to make the equivalent model more precise, source terminal impedance and load impedance[17] are added in the figure. Namely, two voltage sources are added to linear network to simplify the whole circuit as 3+2 ports.

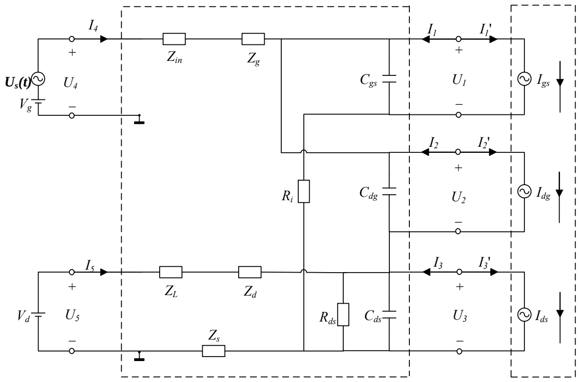

Fig. 4 Equivalent model for large signal of decomposed PID fuzzy control algorithm

$\boldsymbol{I_{nk}}$ indicates the vector quantity of k-order harmonic component on port n in linear network; the current of nonlinear network is decided by the nature of port voltage and nonlinear element and $\boldsymbol{I'_{nk}}$ indicates the current of nonlinear network.

The current of linear network is:

$$\boldsymbol{I} = \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} + \begin{bmatrix} Y_{14} & Y_{15} \\ Y_{24} & Y_{25} \\ Y_{34} & Y_{35} \end{bmatrix} \begin{bmatrix} V_4 \\ V_5 \end{bmatrix} \tag{4}$$

Where, admittance parameter Y_{ij} can be obtained from equivalent parameter for small signal, namely, $Y_{ij} = \mathrm{diag}[Y_{m,n}(k\omega)]$, $i = 1,2\cdots 5,\ j = 1,2\cdots 5,\ k = 0,1\cdots 3$.

Time domain expression of nonlinear current is converted to frequency domain through Fourier transform and other simplified methods and the vector of frequency domain is obtained, then:

$$\boldsymbol{I}' = \begin{bmatrix} I'_1 \\ I'_2 \\ I'_3 \end{bmatrix} = \begin{bmatrix} I_{gs} \\ I_{dg} \\ I_{ds} \end{bmatrix} \tag{5}$$

Harmonic balance equation is obtained through Kirchhoff's current law (KCL), then:

$$\boldsymbol{F}(\boldsymbol{V}) = \boldsymbol{I} + \boldsymbol{I}' = 0 \tag{6}$$

Improved hybrid genetic algorithm is adopted to solve the system of nonlinear equation through iteration. Initial values V_1, V_2, V_3 of iteration are calculated with PID parameter method and g-d-series current I_b can be ignored at the time of calculation. Initial values are put in Equation (5) to solve the current of linear network. Admittance matrix of Formula (5) is obtained through equivalent parameter for small signal. Nonlinear current is obtained through Fourier transform. Finally, linear current and nonlinear current vectors are put in Equation (6) and final exact solution is obtained through iterative operation. Current and voltage values on any element can be obtained through this set of solutions and results contain multiple harmonics, which can describe nonlinear phenomenon in the circuit satisfactorily.

III. SYSTEMATIC DESIGN METHOD OF PID FUZZY CONTROLLER

To overcome these inadequacies of genetic algorithm, a new hybrid genetic algorithm is proposed in the Thesis. The algorithm combines PID parameter method, genetic algorithm and quasi-Newton algorithm and divides into initialization, global optimization and local optimization. It can solve the solution of harmonic balance equation with larger probability, with less number of iterations and high calculation efficiency, and can improve and overcome defects of genetic algorithm in low calculation efficiency, easiness to fall into locally optimal solution and calculation quantity increased by derivation and inversion operation of Newton method and effectively enhance the calculation efficiency of algorithm.

A. Initialization

PID parameter method overcomes the defect of power series, introduces memory effect and can describe nonlinear component at all orders of the system respectively. Precise description of system nonlinearity can be achieved only with the first three terms. The thinking of solving initial population with PID parameter method is: voltage at both ends of nonlinear conductance is calculated and precise description can be achieved only with the first three terms. Hence, we only calculate till the third order, namely $k = 3$; then we take voltage component obtained as a unit in initial population and conduct encoding according to real number encoding principle; the process is repeated until the number of population is *N*.

Specific initialization procedure is as follows:

Step 1: calculate linear response, namely:

$$V_1 = \frac{1}{G + g1} \sum_{k=-3}^{k=+3} I_{S,k} e^{j\omega_k t}, \quad I_{S,k} = \frac{V_{S,k}}{R} \tag{7}$$

k is the number of harmonic and we can find the result of single-tone input in Equation (7). The second-order nonlinear current component can be solved with the first order voltage component.

Step2: calculate the second-order nonlinear current and voltage, namely:

$$I_2 = \frac{1}{G + g_1} \sum_{\mathrm{k}_1=+1}^{\mathrm{k}_1=-1} \sum_{\mathrm{k}_2=+1}^{\mathrm{k}_2=-1} I_{S,k_1} I_{S,k_2} e^{j\left(\omega_{k_1} + \omega_{k_2}\right)t} \tag{8}$$

As input current source only has the first-order response, we can solve the second-order with zero input response.

$$V_2 = \frac{-g_2}{4(G + g_1)^3} \sum_{\mathrm{k}_1=+1}^{\mathrm{k}_1=-1} \sum_{\mathrm{k}_2=+1}^{\mathrm{k}_2=-1} I_{S,k_1} I_{S,k_2} e^{j\left(\omega_{k_1} + \omega_{k_2}\right)t} \tag{9}$$

Step3: calculate the third-order nonlinear current and voltage. Similarly, it is also solved with zero input response.

$$\begin{aligned} I_3 = 2g_2 \frac{-g_2}{4(G + g_1)^3} \sum_{k_1=+1}^{k_1=-1} \sum_{k_2=+1}^{k_2=-1} I_{S,k_1} I_{S,k_2} e^{j\left(\omega_{k_1} + \omega_{k_2}\right)t} + \\ \frac{1}{2(G + g_1)} \sum_{k_1=+1}^{k_1=-1} I_{S,k} e^{j\omega_k t} + g_3 \frac{1}{8(G + g_1)^3} \\ \sum_{k_1=+1}^{k_1=-1} \sum_{k_2=+1}^{k_2=-1} \sum_{k_3=+1}^{k_3=-1} I_{S,k_1} I_{S,k_2} I_{S,k_3} e^{j\left(\omega_{k_1} + \omega_{k_2} + \omega_{k_3}\right)t} \end{aligned} \tag{10}$$

$$V_3 = \frac{-I_3}{G + g_1} \tag{11}$$

Step4: calculate sums for obtained the first-order, the second-order and the third-order components and obtain a unit of initial population and conduct encoding. Repeat the process until the number of population is *N*.

B. Local Optimization

As genetic algorithm is prone to fall into locally optimal solution and operation efficiency in later stage of iteration is relatively low, the Thesis adopts quasi-Newton algorithm for local optimization operation after global optimization operation. Quasi-Newton algorithm is characterized with fast convergence rate and it has strict requirements for initial value. When it is far away from exact solution, it is not convergent. When it is close to the exact solution, its convergence rate is fast. However, compared with Newton method, it avoids derivation and inversion process, simplifies solution process[23] and significantly improves calculation efficiency.

The Thesis adopts BFGS correction formula which is the most effective method in quasi-Newton algorithm, namely:

$$B_{k+1} = B_k + \frac{y^k\left(y^k\right)^T}{\left(y^k\right)^T s^k} - \frac{B_k s^k\left(s^k\right)^T B_k}{\left(s^k\right)^T B_k s^k} \qquad (12)$$

Specific calculation procedures are as follows:

Step1: take superior solution obtained by genetic algorithm as initial value V^0, set up maximum allowable precision ε. Let initial approximate matrix $\boldsymbol{H^0} = \boldsymbol{I}$, $k = 0$.

Step2: calculate $g^k = \nabla f\left(V^k\right)$. If $\left\|g^k\right\| \le \varepsilon$, then the algorithm ends and V^k is the approximate solution output to satisfy precision requirements; otherwise, turn to step 3.

Step3: calculate searching direction dir^k, let $dir^k = -H^k g^k$.

Step4: make use of step length factor α^k satisfying retreating step length rules and obtain new iteration point V^{k+1} through the method of line searching, namely $V^{k+1} = V^k + \alpha^k d$.

Step5: calculate g^{k+1}, calculate new approximate matrix H^{k+1} through BFGS correction formula and let $s^k = V^{k+1} - V^k$, $y^k = g^{k+1} - g^k$, $k+1 \Rightarrow k$, turn to step 2.

C. Specific Process of Solving Equation

The flow diagram of overall algorithm is shown in Fig. 5.

Step1: initialize, generate initial population and conduct encoding according to real number encoding rules; set up population size *N*, maximum number of iterations of genetic algorithm *D*, genetic operator and target fitness θ.

Step2: evaluate each unit in the population and set up fitness function as:

$$\begin{cases} \text{find} : x = \left[x_1, x_2, \cdots, x_n\right] \\ \min : \boldsymbol{fit(x)} = \sum_{i=1}^{n} \left|f_i(x)\right| \end{cases} \qquad (13)$$

Calculate the fitness η_i, $i = 1,2 \cdots N$ of each unit through fitness function. If the fitness of certain unit $\eta_i \le \theta$, $i = 1,2 \cdots N$, turn to step 4 and conduct local optimization; otherwise, you should turn to step 3.

Step3: evolution population. Conduct selecting operation, crossover operation and mutation operation for original population with genetic algorithm to form new population. When the number of iteration reaches maximum number of iteration *D* of genetic algorithm, turn to step 4; otherwise, you should turn to step 2.

Step4: conduct local optimization for superior solution obtained with genetic algorithm. Take superior solution as initial value of quasi-Newton algorithm and continue iteration. If precision ε is satisfied, the algorithm ends; otherwise, you should turn to step 3.

IV. SIMULATION AND DATA ANALYSIS

To inspect the performance of improved algorithm in harmonic detection, the Thesis uses equivalent model parameter for small signal and equivalent model parameter for large signal (as shown in Table 1 and 2) and establish harmonic balance simulation platform through programming in MATLAB environment to single-tone and double-tone harmonic balance simulation analysis for MRF281. The quiescent operating point of pipe is set up as $V_{ds} = 24\text{V}$, $V_{gs} = 4.5\text{V}$. The power amplifier works with type A, with working frequency of 2GHz and input power of 25dBm.

TABLE 1 EQUIVALENT MODEL PARAMETER FOR SMALL SIGNAL

Parameter	Value	Parameter	Value	Parameter	Value
Lg(nH)	0.303	*Rd(Ω)*	1.663	*Cds(pF)*	0.104
Ld(nH)	0.097	*Rs(Ω)*	0.961	*Ri(Ω)*	0.097
Ls(nH)	0.128	*Cgs(pF)*	6.420	*Rds(Ω)*	243
Rg(Ω)	0.319	*Cgd(pF)*	0.107	*gm(mS)*	73.9

TABLE 2 EQUIVALENT MODEL PARAMETER FOR LARGE SIGnal

Parameter	Value	Parameter	Value
Ig0(A)	1.009e(-10)	*af(1/V)*	20.259
ar(1/V)	0.100	*β*	0.247
b	0.099	*λ*	0.007
Ib0(A)	4.099e(-6)	*a*	2.52
VT(V)	-3.979		

We respectively adopt Newton method, quasi-Newton method, hybrid genetic algorithm and improved hybrid genetic algorithm for analysis and number of iterations and allowable error results are shown in Table 3. It can be seen that under the condition of the same allowable error, the number of iterations required by obtaining exact solution for Newton method is 69 and required time is 65.48s; number of iterations required by quasi-Newton method is 31 and required time is 22.28s; number of iterations required by genetic algorithm is 38.8 and required time is 22.72s; number of iterations required by algorithm in the Thesis is 26.8 and required time is 16.12s. It turns out that algorithm in the Thesis significantly reduces number of iterations and time required by calculation and has high calculation efficiency.

TABLE 3 CIRCUIT SIMULATION RESULT

error	times/second			
	Newton algorithm	Quasi-Newton algorithm	Genetic algorithm	Algorithm of the Thesis
10^{-3}	37/34.7	16/10.3	35/21.5	21/14.6
10^{-4}	51/50.3	23/15.6	37/22.3	22/14.7
10^{-5}	68/59.4	29/21.2	37/22.5	27/16.3
10^{-6}	83/84.1	40/31.3	41/23.4	30/16.9
10^{-7}	106/98.9	47/33.8	44/23.9	34/18.1

Fig. 5 and Fig. 6 are respectively iteration curves obtained through genetic algorithm in literature [9] and algorithm in the Thesis. It can be seen from the figure that initial average fitness of genetic algorithm is far away from optimal fitness. When the average fitness is close to optimal fitness, the convergence rate decreases significantly. When average fitness reaches optimal fitness, about 80 times of iteration is required. Initial average fitness for algorithm in the Thesis is close to optimal fitness. When optimal fitness is reached, about 47 times of iteration is required. It can be obtained through comparison with literature [9] that algorithm in the Thesis significantly reduces number of iterations, shortens time required by calculation and has good convergence characteristics and high calculation efficiency.

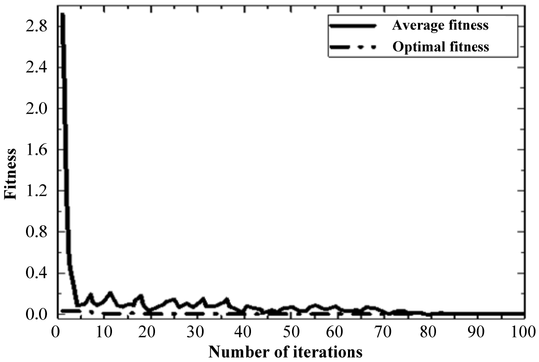

Figure 5. Simulation graph of genetic algorithm

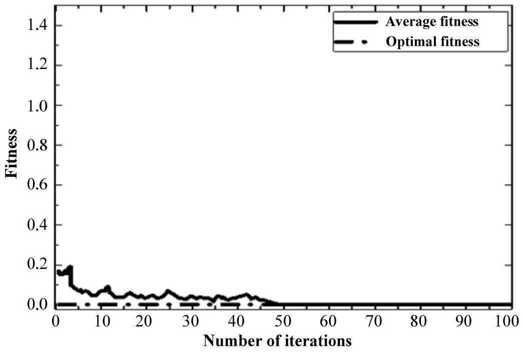

Figure 6. Simulation graph of algorithm of the thesis

Fig. 7 is measured value of harmonic characteristics at the time of inputting 2GHz single-tone signal and simulation curve obtained through algorithm in the Thesis; Fig. 8 is measured value of intermodulation wave characteristics at the time of inputting 1900MHz and 2100MHz double-tone signal and simulation measurement curve obtained through algorithm in the Thesis. In the figure, straight line indicates simulation data and point indicates measured data.

It can be seen from Fig. 7 and Fig. 8 that simulation data have the same change trend as measured data and the error is relatively enormous sometimes. It is because that each parameter can not be considered simultaneously in the process of extracting equivalent model parameter for small signal and equivalent model parameter for large signal. So certain section of curve and measured curve fit well and the simulation results of other sections of curve are relatively poor. On the whole, the simulation curve fits well with measured curve and it proves that the algorithm in the Thesis is successfully applied in harmonic balance.

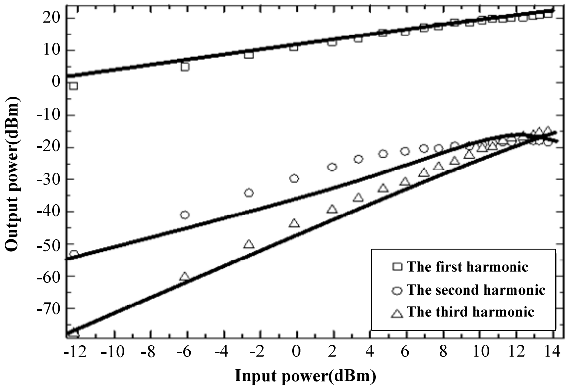

Figure 7. Harmonic characteristics of signal input with single-tone

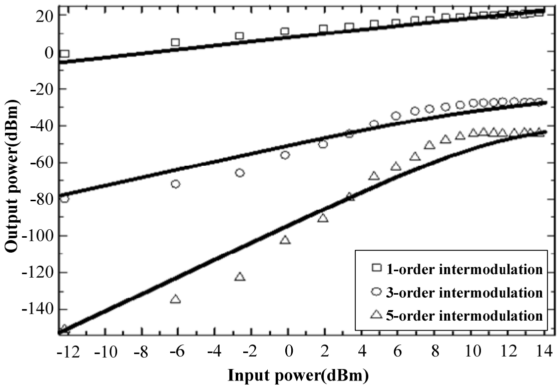

Figure 8. Characteristics of harmonic at all orders of signal input with double-tone

V. CONCLUSION

The algorithm combines PID parameter, quasi-Newton algorithm and genetic algorithm, firstly estimates initial value of frequency domain with memory characteristics of

PID, then conducts global optimization with genetic algorithm and finally conducts local optimization with quasi-Newton algorithm. Simulation results based on MRF281 harmonic balance show that compared with genetic algorithm, number of iterations of the algorithm decreases by about 40% and simulation data fit well with measured data. Improved algorithm has the characteristics of global optimization and local optimization, significantly improves precision and convergence rate, overcomes defects of large randomness and weak local searching capacity of genetic algorithm and has great reference value for nonlinear circuit analysis.

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