IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received June 23, 2020, accepted July 1, 2020, date of publication July 14, 2020, date of current version August 5, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.3009240

On-Line PID Parameters Optimization Control for Wind Power Generation System Based on Genetic Algorithm

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This work was supported in part by the Hunan Provincial Natural Science Foundation of China under Grant 2017JJ2023 and Grant 2020JJ4158, and in part by the Scientific Research Fund of Hunan Provincial Education Department under Grant 18A407 and Grant 19A084.

ABSTRACT An on-line PID parameter optimization control for the wind power generation system based on a genetic algorithm is proposed in this paper. Firstly, the anti-saturation PID control strategy is involved with considering the instability and complexity of the wind power source. Further, a genetic algorithm is introduced for an on-line optimization of the PID parameters. The simulation studies are carried out on a control model of wind power, using MATLAB simulation system. It is demonstrated that the proposed control strategy can not only solve the integral saturation, but also suppress the harmonics in the output waveform and enhance the power factor of system.

INDEX TERMS Anti-saturation, genetic algorithm, online optimizing, PID parameters.

I. INTRODUCTION

Nowadays, owing to the shortage of fossil energy, the wind power is considered as a primary candidate of the primary energy source in the future. However, an instability of the wind power brings a great challenge for the practical applications [1]–[5]. It is therefore necessary to find an effective control method to address this issues aforementioned above.

Many researchers have focused on the wind power. In [6], a control algorithm was proposed to realize the maximum wind energy tracking by using a rotational inertia power of a rotor. The proportional controllers in [7], [8] were added to a traditional power control algorithm, which speeded up to capture a wind energy. A review of the currently applied methods of a wind power generation forecasting was presented in [9]. Due to different properties of the input data, there are some difference between the physical and statistical methods. The physical method is usually based on numerical weather prediction models, using data related to atmospheric conditions, terrain, and wind farm characteristics. However, the statistical method uses historical data sets to determine the dependence of output variables on input parameters. From the perspective of the quality of results, the hybrid methods are the most favorable ones. Determining the best model depended on many factors is a complicated task. The applied model may be highly accurate at given conditions, but it may be completely unsuitable for other wind farm. Reference [10] emphasized on various available harmonic mitigation techniques, which ensured the safeguarding of grid connected doubly fed induction generators from the harmful effects of harmonics. According to the principle of dual power flow wind power generation system and the mathematical model of EVT motor, herein a control strategy of the wind power generation system is presented, including the maximum wind energy tracking control under the rated wind speed, the pitch control above the rated wind speed, EVT Internal rotor speed control, grid-connected power control, energy storage unit charge and discharge control. The dual power flow wind power generation system can effectively mitigate the wind energy fluctuations. As a consequence, wind energy efficiency has been improved. In [11], a nonlinear control method based on sliding mode theory was proposed, which can realize the maximum wind energy tracking control. Reference [12] proposed a multi-resonant PR control in the basis of grid-connected current feedback capacitor current feedback, which can realize no static control of AC

The associate editor coordinating the review of this manuscript and approving it for publication was Yue Zhang.

signal, and can suppress the output current harmonics better when a system is connected to the network. In [13], a corresponding power control strategy for back-to-back converter was proposed, which can effectively suppress the fluctuation of the output power of the wind power generation system due to randomization of wind speed [14]–[16].

From the previous works, one can see that the online control wind power system is not investigated thoroughly. Therefore, combining with the advantages of a genetic algorithm and a PID control, a genetic algorithm (GA) on-line optimization of anti-saturation PID control strategy is proposed in this paper.

II. MODEL OF ANTI-SATURATION PID CONTROL WITH GENETIC-ALGORITHM-BASED ON-LINE PARAMETERS OPTIMIZATION

A. THE ANTI-SATURATION PID CONTROL MODEL

Since a wind power system is an unstable nonlinear system, an integral saturation will appear when a traditional PID is used to control the nonlinear system. In this paper, the anti-saturation PID control strategy is adopted, as shown in Fig. 1. Here u_n is a PID output, u_s is a system output, k_i, k_p, k_d is the differential, integral and proportional factors, respectively. Based on the traditional PID control principle, a control input saturation error is integrated by u_n-u_s in Fig. 1. Then an adaptation coefficient is loaded into the integral term of a PID system based on the following rule.

$$\varphi = \begin{cases} -\alpha(u_n - u_s)/k_i, & u_n \neq u_s, e(u_n - \overline{u}) > 0 \\ e & u_n = u_s \end{cases} \quad (1)$$

where $\overline{u} = (u_{\min} + u_{\max})/2$, $\alpha > 0$, and $u_{\min}$and $u_{\max}$are the maximum and minimum value of a controlling input signal respectively.

Hence, the anti-saturation PID control can be expressed by

$$u(t) = k_p e(t) + k_i\varphi + k_d {}^{de(t)}/_{dt} \quad (2)$$

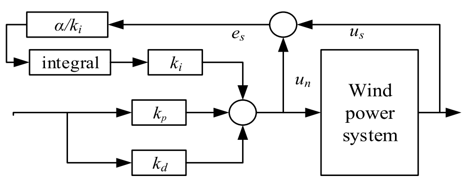

FIGURE 1. Structure chart of anti-saturation PID controlling.

B. GENETIC ALGORITHM PRINCIPLE

Genetic algorithm is a random searching algorithm based on biology natural selection and genetic mechanism. The proposed search begins from the initial solutions of a group of random population, where each one is a solution of the problem and is named as chromosome which is actually a string of symbols. These chromosomes evolve continuously in the subsequent iteration called heredity. In each generation, the chromosomes is assessed by fitness, and the generated chromosome is called offspring which is formed from the crossover or variation operation.

In the formation of a new generation, to keep a constant population size, some offspring are chosen and others are weeded out according to their moderate size. It should be noted that the chromosomes with high fitness are easy to be chosen. After a number of generations, the algorithm will converge on the best chromosome that probably is the optimal or second-best solution.

C. THE IDEOLOGY OF THE GENETIC-ALGORITHM-BASED PID PARAMETERS OPTIMIZATION

In the control of a wind power generation system, the control parameters must keep changing to achieve an optimal output due to the instability of a whole system. The optimization of PID controller is used to decide a group of k_p, k_i and k_d to achieve the optimal index, and the integral of square error (ISE), integral of absolute error(IAE), integrated time and absolute error(ITAE)and integral of time square error(ISTE) are the common error performance indexes. In these error performance indexes [17], the ITAE is a kind of performance evaluation index with best engineering practicality and selectivity. In this paper, the ITAE error performance index is selected. The ITAE is applied in this paper because of its well project practicability and selectivity [18]–[20]. The ITAE is defined as

$$J = \int_0^\infty t\,|e(t)|dt \quad (3)$$

For optimal manipulation of a wind power system, it is necessary to select an appropriate algorithm to optimize the PID controller parameters. At present, there are many optimization algorithms, such as GA, particle swarm optimization (PSO), fuzzy self-adaptation (FS), expert algorithm (EA), and iterative learning (IL). Among them, the genetic algorithm is used to encode the problem parameters into chromosomes for optimization, instead of focusing on the parameters themselves. Therefore, it is not restricted by function constraints. Moreover, the GA has a characteristic of implicit parallel search, which can greatly reduce the possibility of falling into a local minimum. Additionally, the GA is especially suitable for solving the large-scale nonlinear optimization problems. Thus, in the paper, a GA is applied in the optimal design of an anti-saturation PID controller illustrated in Fig. 2. The strategy is illustrated as follows: Firstly, the three PID parameters k_p, k_i, k_d are combined to be the unit of a GA group, and the fitness value of each group is calculated according to the fitness function. Then, choosing, crossing, mutation, and evolution are operated upon these groups continuously until finding the optimal object unit i.e., the optimal parameters of a PID controller.

The genetic-algorithm-based controller consists of two parts, i.e., the PID controller that directly controls a wind power system in close-cycle with dynamically optimized k_p, k_i, k_d; and the GA that adjusts the parameters of a PID controller according to the system status [21]–[24].

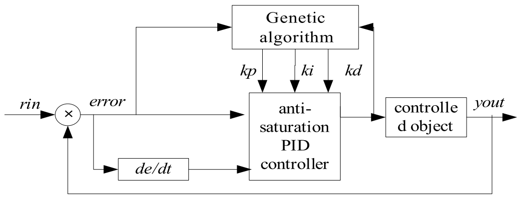

FIGURE 2. Structure chart of genetic algorithm optimizing PID controller parameter.

The implementation procedure of the genetic-algorithm-based optimizing PID parameters is realized concretely through four steps as follows.

Step 1: The certain scale initial group is generated based on an even-crossing design method around the PID controlling three parameters value adjusted by a Z-N method [25].

Step 2: The fitness of each unit in a group are calculated according to the reciprocal of formula (3).

Step 3: New populations are generated through the crossing selection and mutation operation.

Step 4: The fitness of new populations is calculated based on the method represented in step 2. If a new population satisfies the terminal condition, which means that an optimal parameter is found, and the result will be output. Otherwise, go back to step 3.

The detail process is presented in Fig. 3.

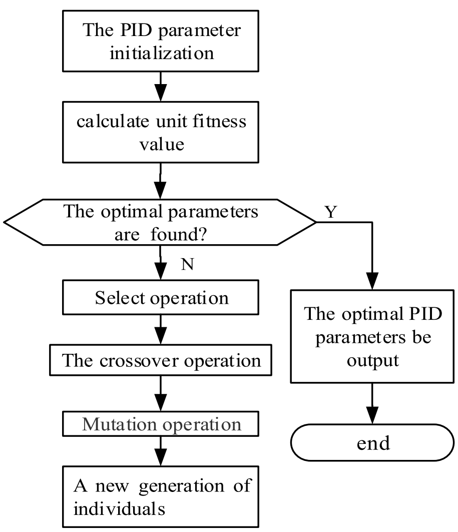

FIGURE 3. Procedure chart of genetic-algorithm optimization of anti-saturation PID controller.

III. SIMULATION TEST AND ANALYSIS

A. SIMULATION COMPARISON BETWEEN COMMON PID CONTROLLER AND ANTI-SATURATION PID CONTROLLER

To verify the superiority of a proposed strategy, a wind power system with the transfer function of $^{127}/_{(s^2+18s)}$ is controlled by a normal PID strategy and an anti-saturation PID strategy, respectively. The simulation model is shown in Fig. 4, where the input signal is assumed as a big step signal with an amplitude of 10, α is 1, k_p is 58, k_i is 20, and k_d is 3. Besides, chap1_1ctrl and chap1_1xite is the controlling subprogram module and self-adaption coefficient adjustment subprogram module, respectively, and Manual Switch is the chosen switch. If the Manual Switch is turned down, an anti-saturation PID control is applied, otherwise, a common PID control is applied. Further, the phase step response curves and output waveforms of a common PID and an anti-saturation PID are illustrated in Figs. 5-8. From Figs. 5 and 7, it is found that the normal PID control results in the position trailing error which be eliminated by using an anti-saturation PID control. Additionally, from Figs. 6 and 8, the waveforms before saturation and after saturation are very different from each other in a normal PID control, however, they can converge to each other quickly in an anti-saturation PID control. Hence, it is concluded that the integral saturation problem can be addressed through the anti-saturation PID control in a wind power system PID control and stabilize the system rapidly.

B. THE EFFECT OF PARAMETER CHANGING ON THE ANTI-SATURATION PID CONTROLLER

In fact, due to a wind power system instability, a PID control parameters will keep changing. It means that the system performance will be suppressed if the PID parameters are not optimized correspondingly. Furthermore, the simulation is conducted to explain this problem in details. Based on an anti-saturation PID control simulation model mentioned above, the k_p is changed to 55, k_i is changed to 10, k_d is changed to 2, and the corresponding step response curve and output waveform are depicted in Figs. 9 and 10, respectively. Comparing Figs. 7 with 9, one can see that a constant position trailing error is appeared in an anti-saturation PID control with the new parameters, which is different from an anti-saturation PID control designed in last subsection. Moreover, as shown in Figs. 8 and 10, the convergence speed becomes slow after changing the PID parameters.

C. SIMULATION OF GENETIC ALGORITHM OPTIMIZING ANTI-SATURATION PID CONTROILING PARAMETERS

To alleviate the performance degradation caused by the change of PID parameters, a genetic algorithm method is employed to optimize the anti-saturation PID control parameters dynamically. To verify the superior of the proposed method, the simulation model is built by using Matlab. In the simulation, the transfer function of a wind power system is kept the same as the one mentioned in Section 1. Moreover, the sampling time is 1ms, the input signal is a big step signal, the sampling number in a genetic algorithm is 30, and the crossover probability and mutation probability are 0.9 and 0.033, respectively. After 100-generation-evolution, the optimized parameters can be obtained as follows: $k_p = 58.0011$, $k_i = 19.9980$, $k_d = 3.0101$, the performance index $J = 23.9926$. Figs. 11 and 12 show the optimizing process of a cost function, and the step response waveform of an optimized PID controller, respectively. It is demonstrated that

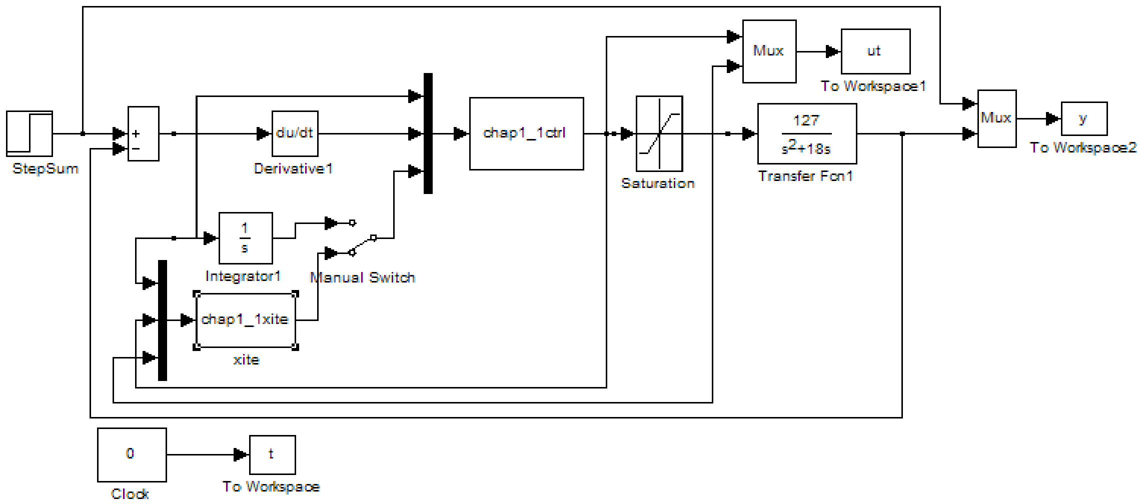

FIGURE 4. Main program chart of anti-saturation PID controlling.

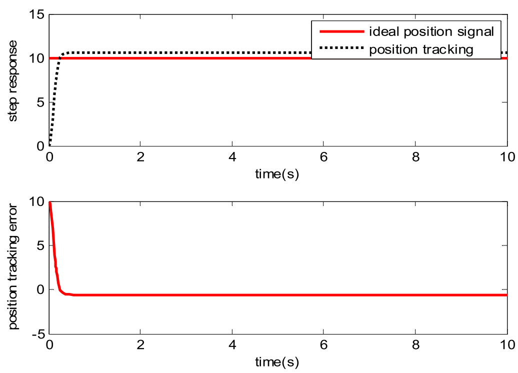

FIGURE 5. Phase step response of common PID controlling.

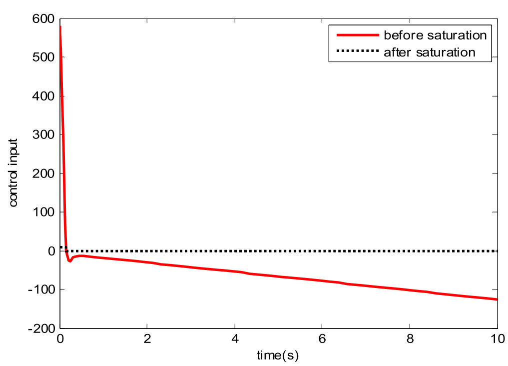

FIGURE 6. Output of common PID controlling.

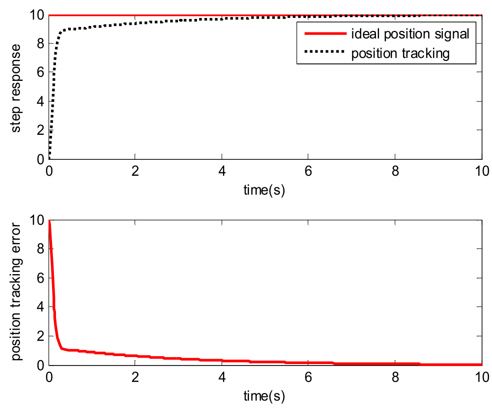

FIGURE 7. Phase step response of anti-saturation PID controlling.

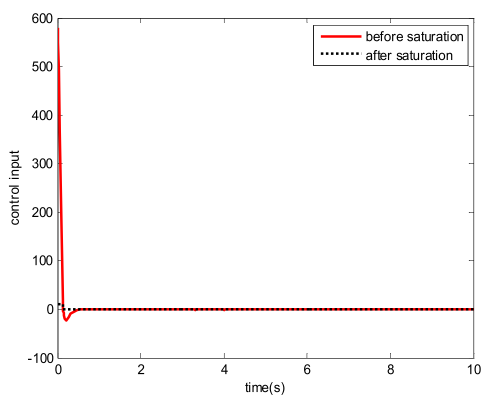

FIGURE 8. Output of anti-saturation PID controlling.

the proposed controller can achieve the optimal performance based on the online optimized parameters.

D. SIMULATION OF WIND POWER GENERATION SYSTEM BASED ON THE ON-LINE PARAMETER-OPTIMIZATION PID CONTROL

To illustrate the superiority of the proposed algorithm, the simulation is carried out in the Matlab. Fig. 13 presents the voltage and current waveforms of the AC side and DC side applying the proposed algorithm, where the horizontal coordinates are time t, the vertical coordinates in are input current i_i, and the vertical coordinates below are u_i and u_o, and the corresponding FFT results are shown in Fig. 14. It is found that the THD of output waveform of system based

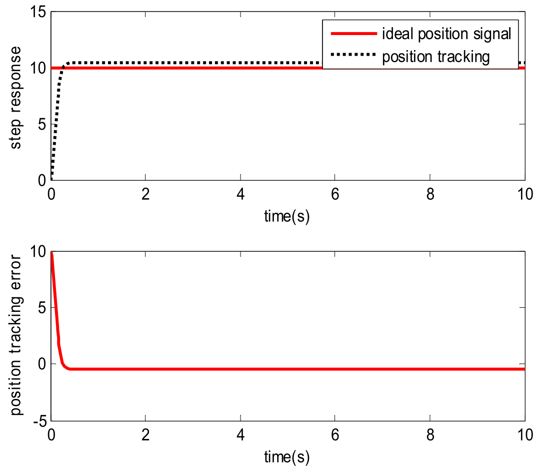

FIGURE 9. Phase step response of anti-saturation PID controlling after changing parameters.

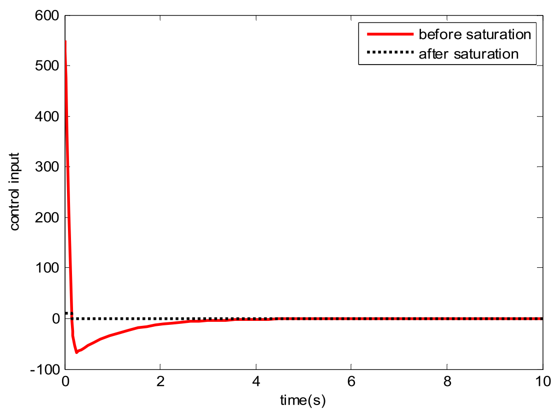

FIGURE 10. Output of anti-saturation PID controlling after changing parameters.

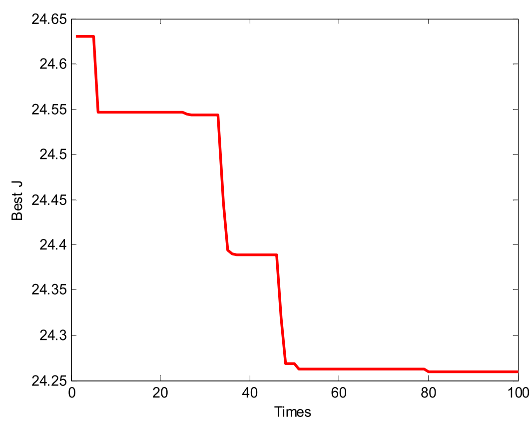

FIGURE 11. Optimization procedure chart of cost function.

on the proposed method is only 4.82% which is obviously better than the conventional value 15.58%. In other words, the proposed method can realize a harmonic suppression. Besides, Fig. 15 shows that the current and voltage phase angle are 27.73 and 25.69, respectively, and the active and reactive power are 13045.67W and 471.37Var, respectively. It means that the power factor is 0.9993 that is very close to 1.

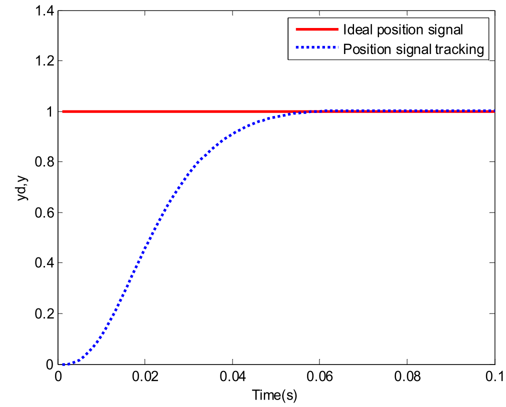

FIGURE 12. Phase step response waveform of PID controller after optimization.

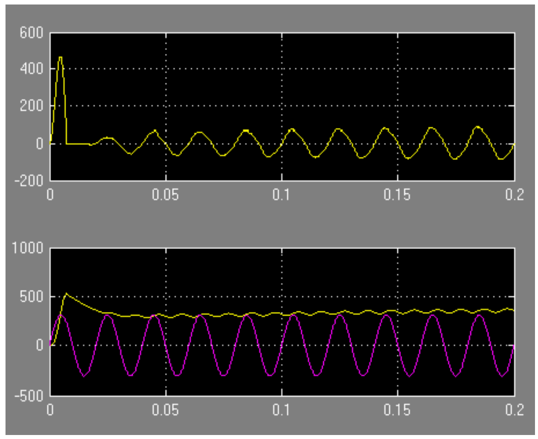

FIGURE 13. The waveforms of u_i, i_i and u_o.

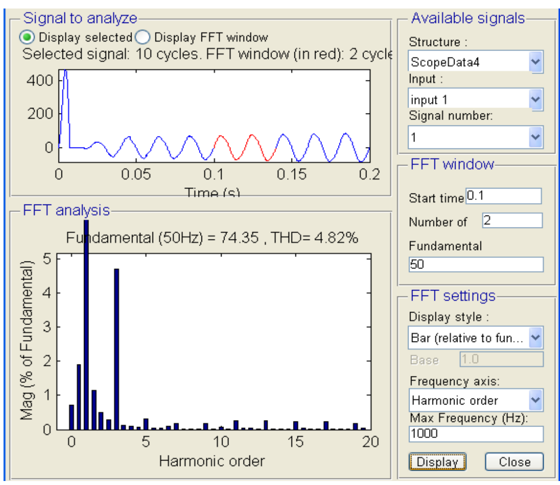

FIGURE 14. FFT analysis results.

Hence, it is reasonable to declare that the proposed method can improve a power quality greatly.

IV. EXPERIMENTAL TEST AND DATA ANALYSIS

To verify the feasibility and practicability of GA, Using the FPGA Development Board as the main core component, an experimental prototype is made, and combining with the

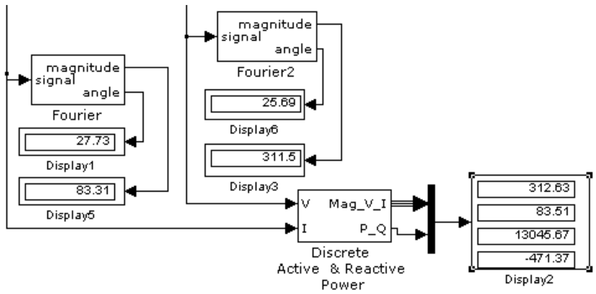

FIGURE 15. Current-voltage fundamental phase angle and active-negative measured values.

DSP builder and Quartus2 software, the related Matalab program is converted into VHDL hardware description language, loaded into the experimental prototype and tested in practice. The equipment used is the Fluke 1760 three-phase power quality recorder of Fluke Corporation. The GA control method is compared with PSO, FS, EA, Il on PID control of a wind power system, as shown in Table 1. From table 1, GA is suitable and practical to control the wind power generation system by optimized PID parameters.

TABLE 1. Optimization algorithm comparison.

	PSO	FS	EA	IL	GA
THD	8.31%	13.63%	19.53%	10.09%	4.82%
The power factor	0.9647	0.9095	0.9190	0.9356	0.9993

To better explain the problem, the proposed method is applied to different wind power systems, and compared with the traditional method to test and analyze the results. Table 2 shows the THD comparison of the two methods in several different models, Table 3 is the comparison of power factor. From tables 2 and 3, it is found that the proposed method can improve the power factor and the power quality and reduce the harmonic distortion rate greatly.

TABLE 2. THD comparison.

	model 1	model 2	model 3	model 4	model 5
Traditional method	15.58%	13.63%	12.67%	14.21%	16.03%
The proposed method	4.82%	5.56%	7.83%	4.09%	5.32%

TABLE 3. The power factor comparison.

	model 1	model 2	model 3	model 4	model 5
Traditional method	0.8987	0.9782	0.8992	0.9218	0.8897
The proposed method	0.9993	0.9965	0.9897	0.9991	0.9986

V. CONCLUSION

To alleviate the performance degradation caused by the instability of a wind power, an on-line PID parameter optimization control method based on a GA is proposed for a wind power generation system. Firstly, the specific features of a wind power are analyzed, and an anti-saturation PID controlling is involved to solve the integral saturation of a wind power generation control system. Moreover, a genetic algorithm is introduced to alleviate the impact of instability of a wind source on the system performance. Finally, based on the Matlab software platform, a simulation model is built and carried out. The test results on a control model of wind power show that the proposed anti-saturation PID controller with a genetic-algorithm-based on-line parameter optimization can not only improve the system stability and convergence speed, but also enhance the power quality of a system output.

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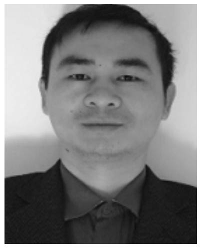

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