Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.22, September 2024

The Monitoring and Analysis of Protective Devices in Renewable Energy Resource Grid by Computer Simulation Technology

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Abstract. Nowadays, computer simulation technology is very important in promoting the economic development of renewable energy, but simulation technology cannot effectively identify grid protection devices, so it needs to be identified with the help of optimization algorithms. This study focuses on the inspection and evaluation of protective equipment in renewable energy grids and constructs a micro-power unit control algorithm to identify the retention status in renewable energy grids. First, the static and dynamic conditions will be distinguished, and the differences between the preservation devices will be explored by computer data identification through micropower. The relationship structure between computer simulation technology and renewable energy is established, and the reliability of the relationship structure is calculated, so as to provide a reference for the identification and application of protective devices. The results show that the micropower algorithm can provide effective data for computer simulation technology, better identify protective devices, improve the degree of data fusion by about 10~20%, increase the recognition rate of abnormal data by about 10%, and reduce the amount of computer simulation data. Therefore, the integration of micropower algorithm and computer simulation technology can more accurately simulate close to the real environment, which can not only improve the accuracy of device detection, but also evaluate and optimize the detection effect, and provide key practical support for renewable energy grid protection.

Key words. Computer Simulation Technology, Renewable Energy Grid, Protection Device, Monitoring and Analysis.

1. Introduction

The effective use of renewable energy, such as wind and solar energy resources, can successfully cope with the problem of electricity consumption in places or islands far from the main power system, and play a key role in green economic growth and energy regeneration [1]. At present, photovoltaic and wind power have their own advantages and implementation conditions and need to carry out environmental and on-site simulation, so the issue of computer simulation of renewable energy has attracted much attention and has become a major part of the national renewable energy development strategy [2]. Computer simulations are able to identify differences in the way renewable energy is generated, predicting significant differences in power generation. However, under the actual sunshine, wind speed and climatic conditions, computer simulation technology has problems such as a large amount of computing data and a high complexity in establishing and simulating renewable energy grids [3], which cannot provide support for protection devices. For the high-power grid-connected power generation system, this paper uses the micro-power optimization algorithm to analyze the stable waveform of the inverter, the proportion of grid-connected current harmonic change, and the dynamic response of the current controller in the grid-connected renewable energy system, so as to realize the prediction of micropower.

Based on this background, this study uses computer simulation as the cornerstone to creating an independent protection device monitoring model that combines software and digital computer simulation models, including the photovoltaic power generation system model and wind power generation system model. In this study, three scenarios of light fluctuation, power restriction and low voltage channel of photovoltaic power generation system were simulated [4]. Similarly, for wind power systems, this study also simulates wind speeds in rising or falling states. Finally, the pure computer simulation model and the computer simulation model are compared, in order to test the accuracy of the hybrid simulation analysis constructed in this study.

2. Fusion Results of Computer Simulation of Protective Devices Modeling and Analysis of Protection Devices in Renewable Energy Grids

A. Fusion Results of Computer Simulation of Protective Devices Modeling and Analysis of Photovoltaic Power Generation System

Figure 1 shows the structural design of the grid-tied PV inverter used in this study [5], [6]. L1 represents the reverse filter of the inverter, R1 is L1 and its additional resistance on the line, R2 and L2 represent the additional resistance and inductance of the line, respectively, and Rd is a passive damping resistor specially designed to prevent the resonance characteristics of the LCL filter.

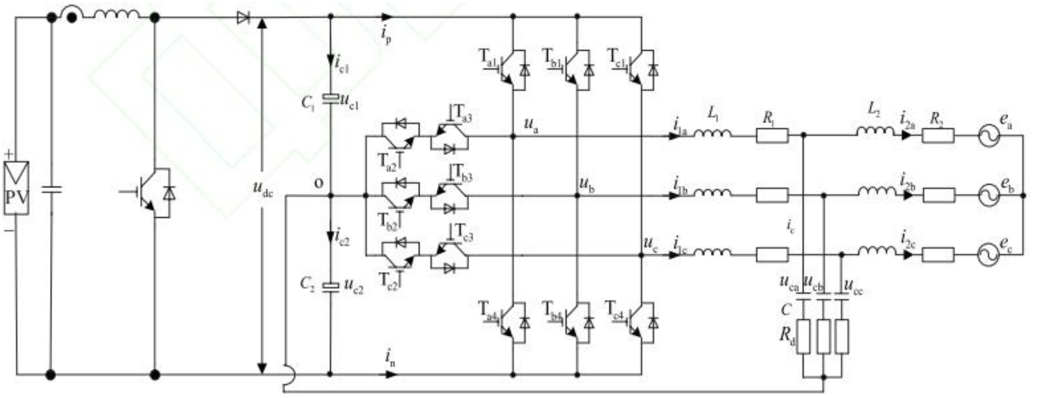

Figure 1. Topology of the Protection Device

In order to better analyze, a switching function Sk(k=a,b,c) was set up:

$$S_k = \begin{cases} 1, & T_{k1} \\ 0, & T_{k2}、T_{k3}, \quad \text{where}, \ k = a,b,c \\ -1, & T_{k4} \end{cases} \qquad (1)$$

If the center O of the DC capacitor is set as the benchmark in this study, then the three-phase voltage of the inverter can be demonstrated:

$$u_{k0} = \frac{1}{2} U_{dc} S_k \qquad (2)$$

In order to refine the interpretation, this study chooses to ignore the influence of Rd when constructing the model and lists the equations of state of the three-level photovoltaic grid-connected inverter, in which the formulas are k=a, b, c.

$$\begin{aligned} u_k &= L_1 \frac{di_{1k}}{dt} + R_1 i_{1k} + u_{ck} \\ u_k &= L_2 \frac{di_{2k}}{dt} + R_2 i_{2k} + e_k \qquad (3\text{-}5) \\ i_{1k} &= i_{2k} + i_{ck} = i_{2k} + C \frac{du_{ck}}{dt} \end{aligned}$$

Based on the synthesis of equations (3), (4), and (5), the state-space equation of the system in the ABC coordinate system can be derived as:

$$\begin{cases} \dfrac{di_{1k}}{dt} = -\dfrac{R_1}{L_1} i_{1k} - \dfrac{1}{L_1} u_{ck} + \dfrac{1}{L_1} u_k \\ \dfrac{di_{2k}}{dt} = -\dfrac{R_2}{L_2} i_{1k} + \dfrac{1}{L_2} u_{ck} - \dfrac{1}{L_2} e_k, k = a,b,c \\ \dfrac{du_{ck}}{dt} = \dfrac{1}{C}(i_{1k} - i_{2k}) \end{cases} \qquad (6)$$

Regardless of the parasitic resistance R2 and inductance L2 of the line, in the steady-state state, ek=uck. If Eq. (6) is applied to the synchronous rotation coordinate system, the equation of state of the grid-tied inverter in the DQ coordinate system can be derived. In this system, the photovoltaic control is completed by the step-up circuit, and the specific control architecture can be referred to in Figure 2.

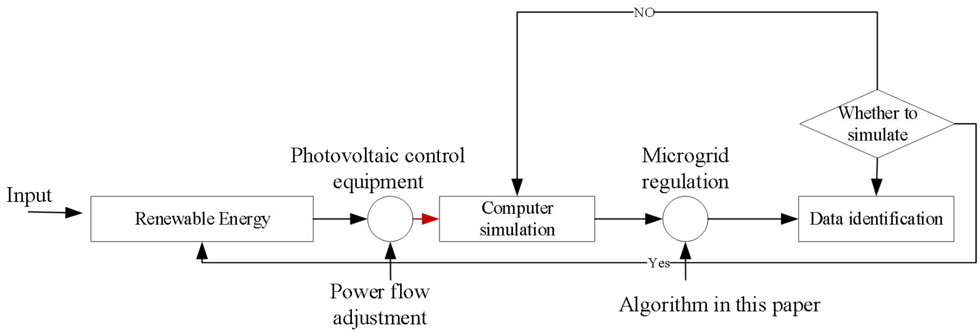

Figure 2. Detection Frame for Protective Devices

B. Computer Simulations Modeling and Analysis of Permanent Magnet Direct-Drive Wind Power Generation System

In this study, a low-voltage penetration experimental platform was built by using high-speed simulation and medium-speed simulation of computer simulation, and two control schemes, voltage stability and uneven voltage drop, were planned to prevent the "peak" of low voltage. In this study, transient voltage protection device monitoring for doubly-fed wind farms was integrated and tested using computer simulations [7], [8]. At the same time, this study also proposes a new control method to deal with the intermittency of active and reactive power in photovoltaic arrays. In addition, the power output of the battery was adjusted, and the accuracy of the strategy was verified by computer simulation. Although the above paper mainly uses pure computer simulation software to simulate and verify the established model or the proposed strategy [9], its accuracy and stability will be significantly affected by the modeling accuracy of the mathematical model of the research system. In addition, they did not consider the relevance of the model to the real-world environment. Sometimes, due to the complexity of the model, the built model may not be accurate enough. Therefore, this study needs to put the actual prototype of the system object into the simulation system for research [10].

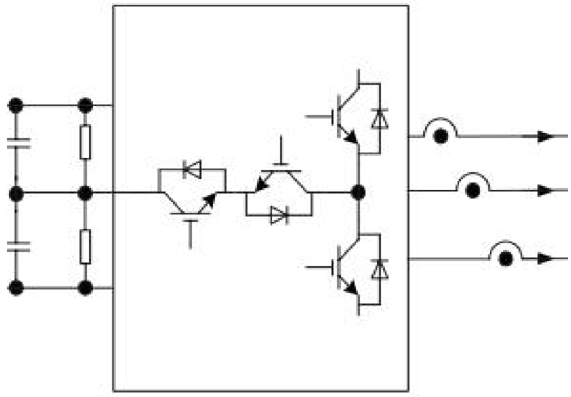

Figure 3. The Implementation Process of the Protection Device

Figure 3 shows the topology of a wind power system. After an uncontrollable rectifier has processed the power generated by the permanent magnet direct-drive generator, the main responsibility of the boost circuit is to increase the input voltage to a higher level while keeping track of the maximum power point. Then, all the energy is directed to the DC area of the inverter, and finally, the advantages of the inverter are used to make the entire power generation system work online simultaneously. In this system, the non-operational rectifier is mainly responsible for converting AC and DC energy, the boost is used to achieve the boost and track the highest power value, and the inverter's role is to keep the DC terminal voltage stable and achieve parallel operation.

3. Analysis of Renewable Energy Grid Protection System Architecture and Communication Architecture

A. *Structural Analysis of Real-Time Simulation System for Wind and Solar Power Generation*

In the computer simulation environment of a wind power generation system, the main electronic equipment such as wind turbines, converters, and transformers, are all in the form of computer simulation, and the control equipment is a real computer simulation control device. The control unit collects information about the voltage, current, wind speed, switching status, and other relevant information about the wind power system to make corresponding calculations. Ultimately, they use a GTDI interface to transmit PWM pulses and switch operating signals to a computer simulation system. As a result, the study completed the overall management of wind power generation equipment. This study fuses them into a small microgrid system to further explore the operational characteristics of renewable energy grid systems. The electrical and mechanical layout of the digital and computer-simulated hybrid renewable energy grid system constructed from the above renewable energy grid system is illustrated.

B. *Communication Architecture Analysis*

The application of computer simulation + intelligent algorithm in photovoltaic power generation system and permanent magnet direct wind system is to connect RS485/Ethernet, and the connection with pure computer simulation models such as energy storage system and load is hardwired to ensure the stability of the system. Figure 4 shows the communication structure of the system.

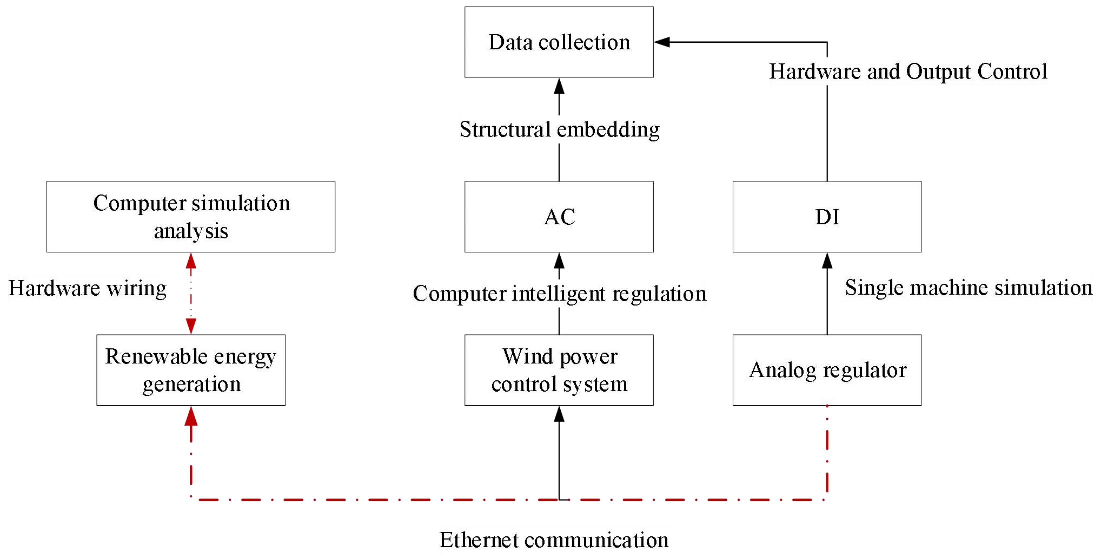

Figure 4. The Monitoring Process of the Protective Device

Although the actual computer simulation test can verify the constructed model more accurately and realistically, and provide an experimental basis for its theoretical exploration, with the expansion of the scale of renewable energy power generation system and the complexity of the model, the construction of a high-power renewable energy power system test platform requires a large amount of investment, the equipment parameters cannot be adjusted freely, and the experimental functions that can be provided are relatively few, and the simulation scope is limited. As a result, it can only offer experiments on specific research topics and lacks universal applicability. At the same time, after being connected to the actual power grid, it isn't easy to carry out some relevant tests to check the interaction between the protection device monitoring and the power grid. For example, operations such as low-voltage pass-through and landing can be performed. The application of computer simulation technology can overcome the shortcomings to a certain extent, so exploring control strategies for renewable energy grid systems has become extremely important. Through digital simulation on the computer software platform, the real renewable energy grid system can be simulated to overcome the shortcomings of computer simulation. The digital computer simulation hybrid real-time simulation environment is closer to the real state of the renewable energy grid-connected system so that the research can not only evaluate and adjust the effect of the control strategy in the renewable energy grid but also significantly reduce the research time of protection device monitoring and save research funds. At the same time, it can adjust the control parameters and strategies in real time, providing a practical basis for the actual renewable energy grid design, so it has great application potential.

4. Monitoring and Analysis of Protection Devices in Renewable Energy Grids by Computer Simulation Technology

A. Computer Simulation Technology Describes the Requirements for the Preservation of Renewable Energy Grids

The test simulation includes a 3D simulation system based on computer simulation and a complex simulation system for the protection equipment of the renewable energy grid. In this simulation system, the core circuit units such as photovoltaic arrays, grid-connected inverters, and frequency converters are all built in computer simulation mode, while the protection system records signals and information by the caching system. The software simulation of computer simulation and the hardware information recording interface are interactively integrated.

B. Changes in the Power Detection of the Protective Device

When the detection of the protective device is increased from 1000 W/m2 to 600 W/m2, it can be observed that the detection results of the two different algorithms are different. The combination of computer simulation technology and intelligent algorithms can provide continuous protection, as shown in Figure 5.

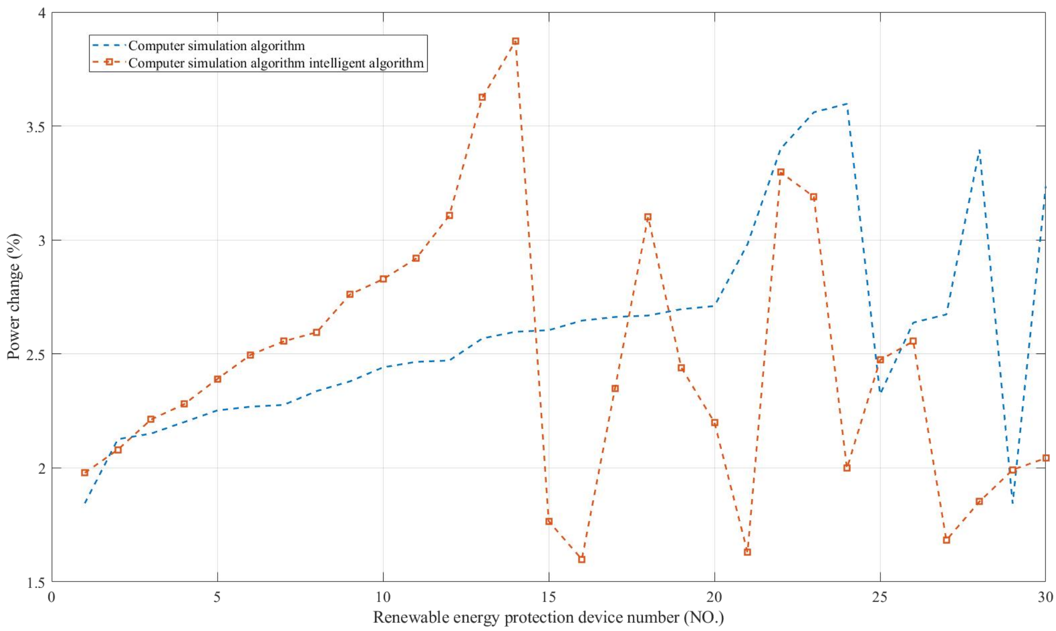

Figure 5. Changes in Power Detection

Figure 5 shows the dynamic active and reactive power waveforms of a hybrid model of computational software and numerical computer simulations. P1 and Q1 are used to describe the power of the protection device, while P2 and Q2 are used to describe the effective and invalid power of the computer simulation model of the protection system.

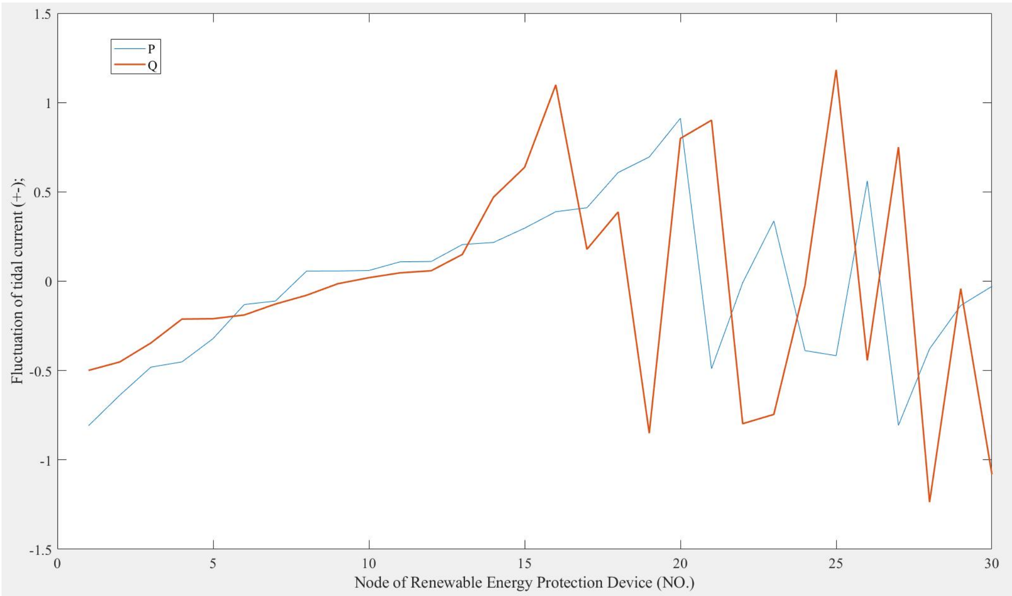

Figure 6. Power Flow Changes in Renewable Energy Grids

It is found that the power flow changes of useful work and useless work show the same direction change and the iterative change and direction and trend between the two are the same, indicating that there is no significant impact on the power grid protection device between the two, and the two are symbiotic, which further shows that computer simulation technology can identify useless work mainly because of the role of its intelligent method. In the time period of 0~2s, the light intensity reaches 1000W/m2, and the effective power output of the two models is not much different. However, within 2 seconds, the light intensity begins to decrease and eventually stabilizes at 600 W/m2. In this process, the output power of the pure computer simulation software model is gradually increased from 30 kW to 15.7 kW, and the adjustment process takes about 1 s. Similarly, the effective power simulated by the computer software increased from 30.2 kW to 14.5 kW, and the adjustment process also took about 1 s, and the dynamic adjustment process between the two was very similar. At the final steady state, the difference in active power between the two is about 1.2kw.

In addition to the accuracy of signal acquisition, propagation delay, and other possible effects, the difference in output power between the two can also be due to a change in the optimal voltage obtained when looking for the optimal power point. This is mainly due to the optimization process of the protection system, i.e., adjusting the voltage at the end of the PV array to achieve the optimization goal. Considering the accuracy of the algorithm, the final voltage will remain near the level of the optimal power point, which causes a change in the final voltage of both, which triggers a change in the output power. In the whole process, the stability of reactive power is high, the reactive power of the pure computer simulation software model is about 0.15kW, and the output reactive power of the computer simulation + intelligent algorithm is about 0.5kW, the difference between the two is not obvious, within the acceptable range, so it can be inferred that the external characteristics of the two models in dynamic operation are about the same.

C. Outlier Identification in Renewable Energy Grid Protection

When the power protection threshold of the renewable energy grid is lowered from 100% to 70%, feedback fluctuations under power constraints can be observed. In the diagram, P1 and Q1 are used to describe the effectiveness and ineffectiveness of computer simulation software models for protecting systems. P2 and Q2 describe the effectiveness and ineffectiveness of digital computer simulation + intelligent algorithms of the protection system.

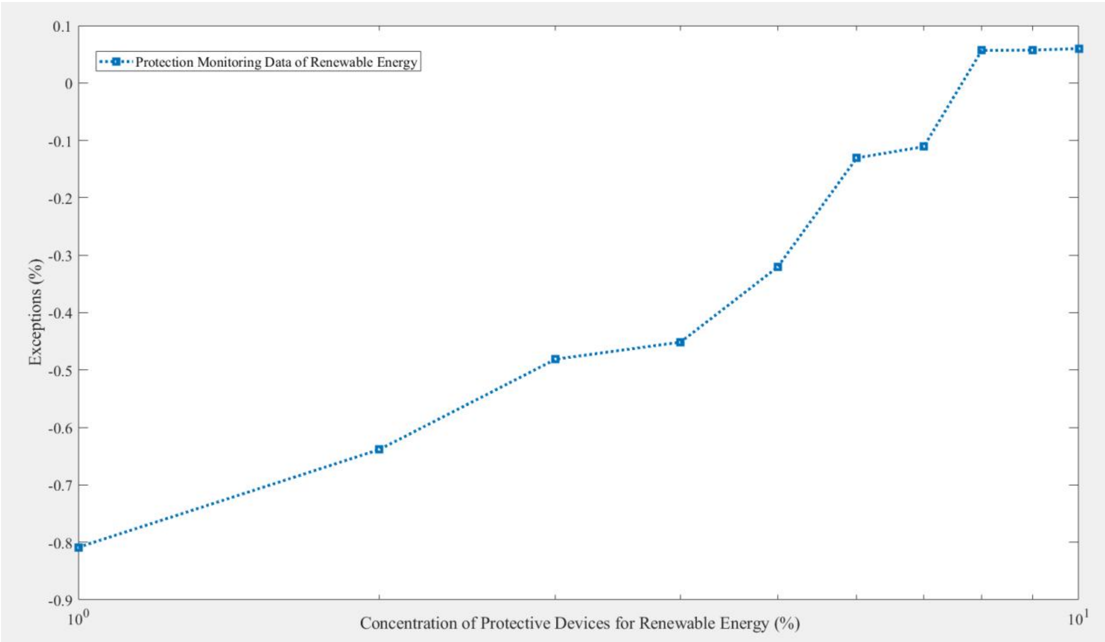

Figure 7. The Degree of Identification of Outliers in the Protection Device

According to Figure 7 restraint, the identification degree of the outlier value of the renewable energy grid protection device gradually increases, and the abnormal change is higher, the time of keeping it in the rated state is 0~2s, and then after 2s, the protection device begins to reduce the rated power, and the difference between different renewable energy sources is only 0.3kW. Therefore, the gap between the two is also quite small, within acceptable limits. From this study, it can be inferred that the characteristics of the protection device are approximately the same when operating at limited power for different methods.

D. Fusion Results of Computer Simulation of Protective Devices

P1 and Q1 are used to describe the effective and ineffective power of the computer simulation software model of the protection system. P2 and Q2 are markers used to describe the effective and invalid power of a hybrid model of a digital computer simulation of a protection system.

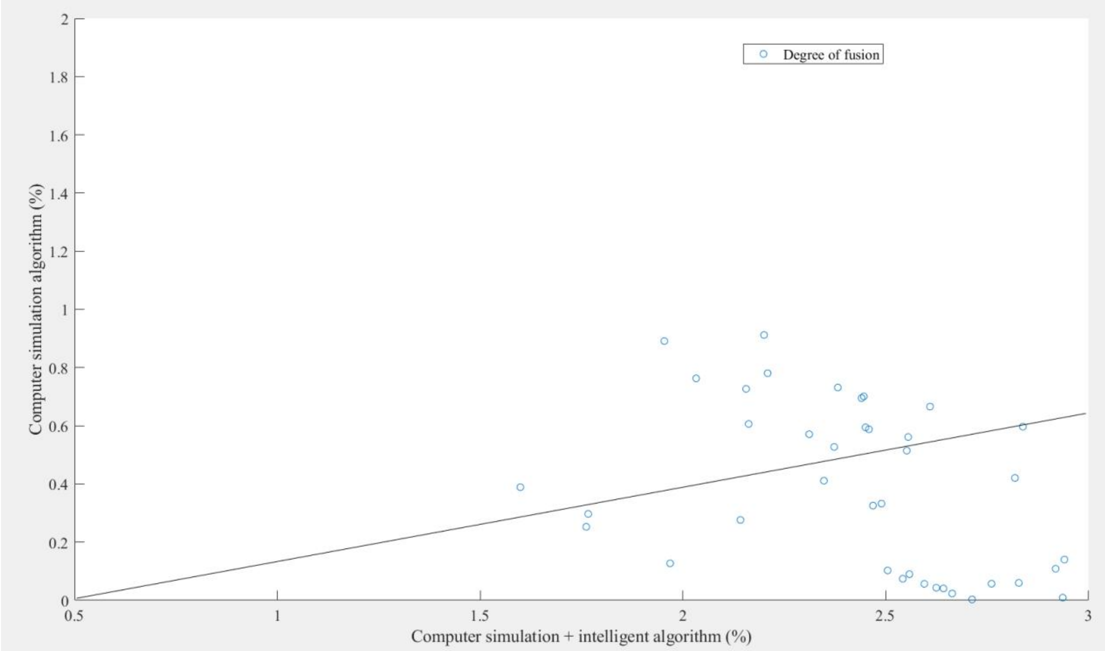

Figure 8. Data Fusion Results of Protection Devices in Renewable Energy Grids

As shown in the data analysis in Figure 8, it can be seen that computer simulation technology combined with an intelligent algorithm can realize the effective monitoring of power protection devices, promote the fusion between data, realize the data unification and standardization of distributed power grids, and lay the foundation for the improvement of accuracy in the later stage, while simple computer simulation technology can not effectively meet the above requirements. Experimental simulation includes pure computer simulation real-time simulation systems and hybrid simulation systems with actual protection devices, such as wind turbines, converters, transformers, etc., which are computer simulation models, and the controller is the actual computer simulation controller. When the wind speed decreases from 11.5 m/s to 9 m/s, the dynamic feedback in Figure 7 can be seen in this study. Figures 7 and 8 show the effective and invalid energies of the computer simulation software model of the permanent magnet direct-drive regenerative energy grid system, while Figures 5 and 6 show the effective and invalid energies of the digital computer simulation + intelligent algorithm of the permanent magnet direct-drive regenerative energy grid system. In computer software mode, the effective power of wind, photovoltaic and hydroelectric parallel is reduced from 25.5 kW to about 11.7 kW. The active power of wind, photovoltaic and hydroelectric power was reduced from 24.6 kW to about 10.8 kW. The power of the parallel effects of the two methods is very well matched, and again, they move in the same direction. However, the output reactive power of the pure and computer simulations is constant throughout the process, at 0.4 kW and 0.7 kW, respectively. When the system is in a steady state, the difference between the effective and invalid power of the two methods is only 0.9 kW and 0.3 kW, which is acceptable for this study, so it can be inferred that the external properties of the two methods are about the same.

The main differences are the differences between the two models in terms of sampling accuracy, signal transmission delay, signal transmission interference, and optimization results. When the wind speed increases from 11 m/s to 13 m/s, the performance of the two modes is shown in Figure 8. In this figure, P1 and Q1 represent the effective and invalid energies of the computer simulation software model of the permanent magnet direct-drive renewable energy grid-connected system, and P1 and Q1 are also the effective and invalid energies of the digital computer simulation hybrid model of the permanent magnet direct-drive renewable energy grid-connected system. The recognition speed of protection outliers of computer simulation + intelligent algorithm is faster, while the recognition speed of active power of computer simulation technology is slightly slower. However, the active power of both models changes in almost the same direction, and the reactive power remains stable throughout the identification period. The maximum active and reactive power differences of 1.5 kW and 0.4 kW respectively during the identification period are acceptable, so the study speculates that their external performance is basically the same.

After previous research, it can be seen that computational software simulation and computer simulation + intelligent algorithms are almost identical in appearance to wind power generation systems, and can be used to characterize various characteristics of the system. However, there are some differences between the two models. Since the calculation software simulates all signals in the computer simulation system, the feedback signal of the protection device is acquired with high accuracy and the device monitoring response is fast, thus reducing the impact of power and voltage changes on the results. However, in the case of computer software simulations, the system must communicate with the actual protection device. Because the acquisition accuracy of the device is limited by the signal transmission, signal transmission delay, and interference in the signal transmission process, the response of the protection device monitoring will be affected, resulting in the difference between the two models. Although the two methods are different, they are still at an acceptable level, and both methods can be used to monitor the protective devices of renewable energy systems such as wind and photovoltaic power.

5. Conclusion

In this study, we present a novel approach that integrates computer simulation with advanced mathematical algorithms for the monitoring of protection devices in renewable energy systems. The primary aim is to address the limitations inherent in traditional software simulations by leveraging the strengths of both simulation and algorithmic processing. By focusing on critical components such as photovoltaic power generation and wind power generation, we developed a robust framework that not only enhances data analysis but also ensures that the results are aligned with real-time operational conditions.

The methodology begins with a comprehensive computer simulation that models various scenarios involving renewable energy generation. This simulation generates a wealth of data, which is then processed using intelligent algorithms designed to perform standard analyses. These algorithms are essential for interpreting the data in a way that provides actionable insights, thus ensuring that the monitoring of protection devices is both efficient and effective.

The success of this approach is demonstrated through extensive simulations, which validate the effectiveness of combining computer simulation with mathematical algorithms. The results indicate that this integrated method significantly overcomes the drawbacks of relying solely on software simulations. Specifically, it improves the accuracy and reliability of calculation results, making them more reflective of real-time detection processes. This is particularly crucial in the context of renewable energy systems, where timely and precise monitoring is essential for maintaining operational integrity.

Beyond merely detecting protective devices, our study introduces the capability to adjust control strategies dynamically. This adaptability is pivotal in environments where conditions can change rapidly, such as in renewable energy systems influenced by variable weather patterns. By implementing real-time modifications to control parameters and strategies, we can drastically shorten the monitoring period for protective devices. This not only enhances the overall responsiveness of the system but also leads to significant cost savings in monitoring efforts.

Moreover, the implications of this research extend to practical applications within renewable energy grids. The ability to monitor and adjust protective devices in real-time provides a strong foundation for the protection of these grids against potential faults or failures. Given the growing reliance on renewable energy sources, ensuring their reliability and efficiency is paramount. Our method offers a scalable solution that can be tailored to various renewable energy setups, thus demonstrating great application prospects in the field.

In conclusion, this study underscores the transformative potential of integrating computer simulation with mathematical algorithms for the monitoring of protection devices. The findings not only highlight the benefits of improved accuracy and efficiency but also emphasize the importance of adaptability in control strategies. As the renewable energy sector continues to expand, the need for innovative monitoring solutions becomes increasingly critical. Our approach stands as a practical and forward-thinking contribution, paving the way for enhanced protection and management of renewable energy grids in the future.

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