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Simulation analysis of energy storage and power system of rooftop solar system[1]

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Abstract. The research on the utilization of solar energy resources was of great significance. The problems of energy storage and power system simulation of rooftop solar energy system were analyzed in this paper. The main contents of digital simulation technology and solar energy storage technology were introduced. At the same time, the main contents and research methods of the solar system as well as the power system model were described. Finally, the research results were analyzed and discussed. The results showed that the parallel computation of power system with serial computation had a good effect, which provided a favorable research direction for the improvement of energy efficiency in the future.

Key words. Solar energy system, power system, energy storage, simulation analysis.

1. Introduction

Tsiganis [1] argued energy storage technology played an important role in improving the stability and power quality of solar energy system. The energy storage device not only can absorb and release a certain power, but also can reduce the network loss of the solar system effectively. At the same time, the energy storage device can also play the most important role in the power system. Vidal [2] considered that energy storage technology included energy storage technology, compressed air energy storage technology, battery energy storage technology and pumped storage technology. Generally speaking, power storage technology had higher power and response speed. Solar energy had low density and poor stability. The energy storage technology can adjust the system load and production cost effectively and improved the utilization efficiency of solar energy to a certain extent in the process of the roof solar energy system. Bhattarai [3] considered that the simulation technology of power system had high accuracy, rapidity and flexibility. Gene rally speaking, the

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digital simulation technology of power system can realize the simulation calculation of power network and adjusted the simulation data reasonably. At the same time, the numerical simulation technology of power system can be combined with other fields such as environment and economy. Nema [4] considered that the simulation experiment of power system can be carried out through several remote experimental equipment, and the main way of simulation calculation was cloud computing and collaborative computing. The application of data fusion technology can integrate the large amount of data in the simulation experiment of power system effectively. In general, the data of simulation experiments were mainly based on linear and nonlinear equations, characteristic equations and nonlinear programming equations to solve and calculate.

In summary, as people paid more and more attention to the use of solar energy, it was very important to study the energy storage and power system simulation of rooftop solar energy system. The energy storage and power system simulation of rooftop solar energy system were analyzed and studied based on the relevant theories at home and abroad in this paper. The connotation of digital simulation technology and solar energy storage technology was expounded in the second section. The main content of the power system and simulation model in the third quarter of rooftop solar energy storage system were introduced, and the research methods of rooftop solar energy storage system analysis and Simulation of power system was discussed in this paper. The simulation data were listed and analyzed in the fourth section. Finally, the conclusions were drawn in the fifth section.

2. State of the art

2.1. Digital simulation technology

Morbidelli [5] thought that the digital simulation of power system is the process of constructing the mathematical model of the power system running by computer and solving the problem by mathematical simulation. There was little difference between the simulation efficiency of the power system and the dynamic efficiency of the actual system. Different simulation requirements needed to build different mathematical models. Figure 1 shows the effectiveness of the power system simulation. Uzunoglu [6] considered that these models included linear or nonlinear, continuous or discrete, lumped or distributed parameters, deterministic or stochastic. However, some of the secondary factors were often ignored in the construction of mathematical models and such models belonged to the simplified model. Different power system simulation software will use different simulation methods based on the different operating conditions of the system. The simulation methods of power system mainly included three kinds of electromagnetic transient process simulation, electromechanical transient process simulation and medium and long term dynamic process simulation. The digital simulation of electromagnetic transient process simulated the real power system by the method of data operation. It was necessary to fully consider the characteristics of the power line parameters and the transient process of the generator and the various characteristics of the lightning arrester in the process of electromagnetic transient simulation. Therefore, the mathematical model of electromagnetic transient simulation must establish the algebraic or differential and partial differential equations of these components and systems. The numerical integration method used in this paper was implicit integration method. Mateus [7] believed that it also involved the transient process of the network and used differential equations to describe so that the simulation of electromagnetic transient simulation program was limited because the electromagnetic transient simulation required not the detailed nonlinear model of the power system dynamic components. In general, the power system was simplified when the electromagnetic transient simulation was carried out.

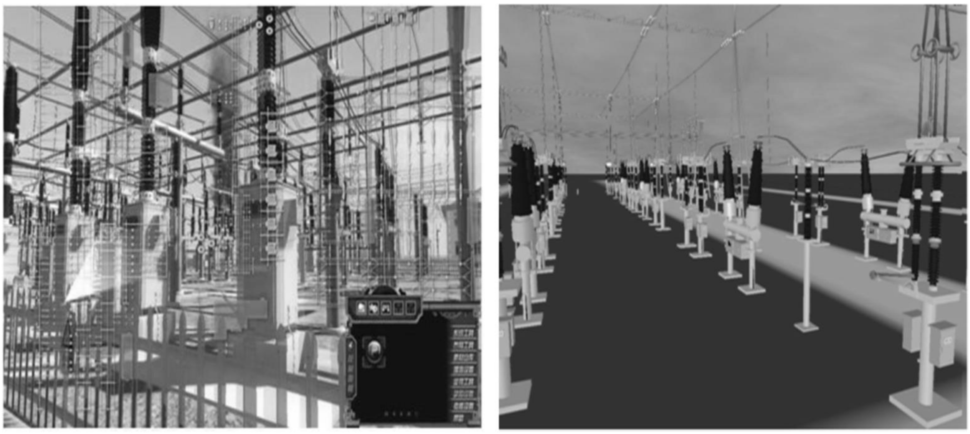

Fig. 1. Simulation results

Raymond [8] believed that real-time simulation of power system can be divided into digital simulation, physical simulation and digital analog hybrid simulation. The simulation speed was exactly the same as that of the actual system. The real time simulation of power system was realized by the simulation system of the moving film. The hardware of the power system dynamic simulation laboratory were usually composed of a number of scaled down motors, a certain number of line models, power supply, load, switch model and corresponding monitoring and control system. Argiriou [9] believed that these devices had high intuitive and rich physical meaning. The price of these devices was high and the area was too large. In addition, the limitations, scalability and compatibility of these devices were poor. The equipment and hardware of power system dynamic simulation laboratory had important function. Most of the components of the digital analog hybrid real-time simulation system were basically the same as those of the power system dynamic simulation system. These components had high flexibility and wide application range. Digital analog hybrid real-time simulation system can simulate the whole process of power system in real time. Digital analog hybrid real-time simulation system had high stability and large simulation scale. Analog and digital hybrid analog circuits, transformers and other components were analog components. The whole simulation system will not produce numerical oscillation when these analog elements and the generator and other digital components were decoupled completely.

2.2. Solar energy storage technology

The integration of solar energy, energy storage and electric vehicles was the trend of new energy development. Solar energy and energy storage technologies had their own advantages. Figure 2 shows the actual scene of solar photovoltaic applications. Gommed [10] believed that solar power can achieve zero carbon emissions without additional costs. Energy storage technology can provide backup power, frequency modulation and other grid services, and the combination of the two can get further advantages. In particular, it can achieve continuous power supply at night, increased the available power generation time and improved the flexibility of the grid. Some authors believe that the combination of solar energy and energy storage technologies in distributed communities and rooftop systems can also reduce the pressure on the distribution network, delayed or reduced infrastructure investment. At the macro level, energy storage and solar power can increase the popularity of solar facilities without major changes, thereby reducing carbon emissions. Energy storage technology combined with solar power can be used as a fast channel for emerging markets electrification. In mature markets, the main drivers for the integration of distributed solar energy and energy storage technologies were cost savings and reduced dependence on the grid. From the cost point of view, the main driving force for consumers or communities to invest in this technology was to reduce electricity bills. Photovoltaic power generation was a leading technology, and can increase the utilization of solar power according to energy storage, thereby increasing economic benefits. The combination of these two technologies was the main driving force to solve the problem of power grid instability in emerging markets. Consumers can enjoy uninterrupted power after buying energy storage system. Solar power can support the energy storage system to extend the power supply time, and further improved the value of the energy storage system. The imbalance of the development of these two technologies has been very obvious. Some parts of Germany, Japan and the United States had economic considerations, and they have adopted rooftop photovoltaic systems quickly, but were not equipped with energy storage systems in most cases. India has established a mature lead-acid battery supply chain to help end users solve the problem of power supply instability in the absence of solar power facilities.

At present, energy storage technology played an important role in the development and utilization of electric energy and new energy. The application of energy storage technology such as pumped storage was large, but the application of other energy storage technologies was limited by economic factors. Energy storage technology can be divided into three categories: physical energy storage, chemical energy storage and electromagnetic energy storage. Different energy storage technologies had different characteristics. Flywheel energy storage, superconducting electromagnetic energy storage and super capacitor energy storage technology can be applied in the case of instantaneous voltage drop and high pulse power. At the same time, these technologies can improve the power quality and power system stability effectively. The application of pumped storage, compressed air energy storage and electrochemical battery storage were suitable for large system peaking and emergency power

Fig. 2. Practical application of solar energy storage

supply, renewable energy into large scale and large capacity etc. Electromagnetic energy storage includes superconducting energy storage, capacitance energy storage and super capacitor energy storage. Superconducting magnetic energy storage system had some advantages in energy storage and transmission power. At the same time, the system also has a higher corresponding speed and conversion efficiency. Superconducting energy storage system can also achieve large number of effective energy conversion. Superconducting energy storage system can meet the requirements of the power grid, such as voltage support, power compensation, frequency adjustment and the ability to lift the system, etc. Super-capacitors were developed according to the theory of electrochemical double layer, which provided powerful pulse power. When the electrode was in an ideal state of polarization, the charge will attract the opposite ions in the electrolyte solution, which was attached to the surface of the electrode to form a double charge layer. Superconducting energy storage system had a wide range of applications. This system can realize the optimization of power quality and power in a short time.

3. Methodology

3.1. Roof solar system simulation mathematical model

The application of photovoltaic technology in solar energy system has led to the development of rooftop photovoltaic devices. At present, China's national science and Technology Commission has begun to develop and optimize the roof solar system into the overall plan of national science and technology gradually. More and more attention has been paid to the effective combination and application of roof solar energy system and building. This is mainly because the system has many obvious advantages. First, the roof solar system covered a small area. Secondly, the system can achieve in situ use and power generation, and reduced the power transmission loss and roof temperature rise to a certain extent. Finally, the system can enhance the beauty of the building to a certain extent and meet the requirements of safe use of electricity.

$$f(u) = I_0 \left\{ \exp \left[\frac{qu}{AKT} \right] - 1 \right\} . \tag{1}$$

Here, u is the voltage, I_0 is the output current, A denotes the diode characteristic fitting coefficient, K is the Boltzmann constant and T is the temperature.

When the light intensity was constant, the photocurrent did not change with the working state of the photovoltaic cell. Therefore, a constant current source can be used to simulate the power system module library and there was no direct current source module. The function of the voltage detection module was shown in formula (1), and the expression of the output value was the formula (2). The simulation experiment was carried out mainly through the MATLAB software for data experiments in this paper. MATLAB application software had great advantages in data calculation and graphic display. In general, it was more convenient to use MATLAB software for data operation and simulation analysis. At the same time, it also had high programming efficiency.

$$u = V + IR_{\mathrm{S}} , \tag{2}$$

where V is the voltage of the PV battery, I is the input current of the diode and R_{S} is the serial resistance.

3.2. Mathematical model of power system simulation

The construction of mathematical model mainly referred to the process of applying mathematics to the physical system. The mathematical model of the system contains diesel engine torque balance model, governor model, synchronous generator model, phase compound excitation device of voltage adjusting model, induction motor load model, static load model, the reactive power compensation device model, emergency alarm system model, power model and so on. In practical power system, the impedance, voltage and current which are connected with the unit property were called the known values. And the rest of the other properties without the unit value were called the value. The reference value was the relative value of the index. The flux linkage equation represented by the scalar value, which was shown in equation (3).

$$\begin{bmatrix} \psi_{\mathrm{dq0}} \\ \psi_{\mathrm{fDQ}} \end{bmatrix} = \begin{bmatrix} X_{\mathrm{SS}} & X_{\mathrm{SR}} \\ X_{\mathrm{RS}} & X_{\mathrm{RR}} \end{bmatrix} \begin{bmatrix} -i_{\mathrm{dq0}} \\ i_{\mathrm{fDQ}} \end{bmatrix} . \tag{3}$$

Here, f denotes field winding, d, q, D and Q represent the rotor and armature axes, φ with appropriate indexes denote the magnetic fluxes and X stand for self and mutual inductances of the rotor and stator.

The electromagnetic torque equation was equivalent to the resistance and inductance of the winding of synchronous motor. At the same time, this equation was based on the assumption of ideal motor to convert the motor into a multi-winding linear electromagnetic system. Among them, the well-known equation for the electromagnetic torque is shown in formula (4). The rotor motion equation was a mathematical explanation of the dynamic process of the rotor system by Newton's law of motion. The equation of motion was one of the basic equations of synchronous generators. The electromagnetic time constant of synchronous generator set was much lower than that of electromechanical time constant. Generally speaking, it was assumed that the unit speed was constant in the calculation of the stator voltage equation in the process of studying the change of the excitation. Under the condition that the rotor speed change was small, the error of the system operation was small. The mathematical model of synchronous generator should be simplified and simulated. The seven order model had a great advantage in describing the dynamic change of the system. These dynamic changes included the transient process of the rotor, the process of the rotor damping winding, the transient process of the excitation winding, the transient process of the shaft winding and the dynamic process of the rotor.

$$T_{\mathrm{e}} = p_{\mathrm{p}} \frac{3}{2} \left(\psi_{\mathrm{d}} i_{\mathrm{q}} - \psi_{\mathrm{q}} i_{\mathrm{d}} \right) . \tag{4}$$

Here, p_{p} expresses the number of pole-pairs, T_{e} denotes the electromagnetic torque, $i_{\mathrm{d}}, i_{\mathrm{q}}$ and ψ_{d}, ψ_{q} are currents and magnetic fluxes in axes d and q, respectively.

The mathematical model was built to ensure the correctness and accuracy of the results. At the same time, the test process of mathematical model was also very important. MATLAB was a kind of application software with high efficiency and high visualization. This software had a strong ability of numerical calculation and graphic display. First of all, we needed to design and test all kinds of graphics control. Then, the simulation system control layout was carried out according to the actual needs. Finally, its characteristics were added and set according to the function of the control in the process of power system simulation system interface design.

4. Result analysis and discussion

The results obtained by the method described above were shown in the following tables:

Table 1. Comparison results of 10 simulation tasks

Serial number threshold calculation task	computing time	Speedup ratio	Parallel efficiency
5	30.403	1.36	0.68
3	35.237	1.17	0.59
2	43.520	0.95	0.48
1	49.516	0.84	0.42

It can be seen from Table 1 that the calculation time, speedup ratio and parallel efficiency of the simulation experiments of the power system when the 10 simulation tasks were parallel. The total computation time of the 10 simulation tasks was 41.381 s, and the optimal time of parallel computation is 30.403 s. The speedup was 1.36, and the parallel efficiency was about 0.68. It can be seen from Table 2 that the computational time, speedup and parallel efficiency of the simulation results of the 50 simulation tasks were parallel. The parallel serial time of the 50 simulation tasks was 211.31 s, and the speedup was 1.65, and the parallel efficiency was up to 0.83. In contrast, the results of the 50 simulation tasks were better than the experimental ones. This was mainly because of the increase of the task to make the simulation process more time-consuming. When the serial threshold was 2 and 1, the efficiency was lower than the serial. It can be seen that serial threshold setting had a direct impact on the parallel efficiency and computing time. A reasonable set of serial threshold can make the simulation tasks be divided equally and achieved the best effect of parallel computing.

Table 2. Comparison results of 50 simulation tasks

Serial number threshold calculation task	computing time	Speedup ratio	Parallel efficiency
25	127.824	1.65	0.83
13	132.036	1.60	0.80
7	142.115	1.49	0.74
4	161.884	1.31	0.65
1	211.862	1.00	0.50

It can be seen from Fig. 3 that the results of the simulation of the rooftop solar system. The data showed that the current, light intensity and temperature were basically the same. The maximum value of the current is 225, which was approximately the same as that of the solar system. We can see from Fig. 4 that the results of the simulation of the power current of rooftop solar system.

The results showed that the trend of power, light intensity and temperature are basically the same. The power between half past eight and half past five PM was more than 6.7 kW, which can meet the requirements of rated power. At the same time, the simulation results showed that the maximum current was not the same as that of the solar system. It can be seen that the variation trend of the current, light intensity and temperature of the solar system were basically the same. At the same time, the trend of power, light intensity and temperature of the roof solar system were basically the same. The power of each period of the simulation experiment can meet the requirement of the rated power.

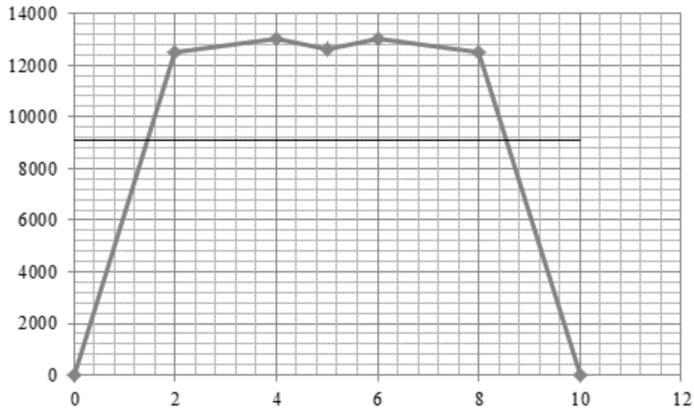

Fig. 3. Current trend

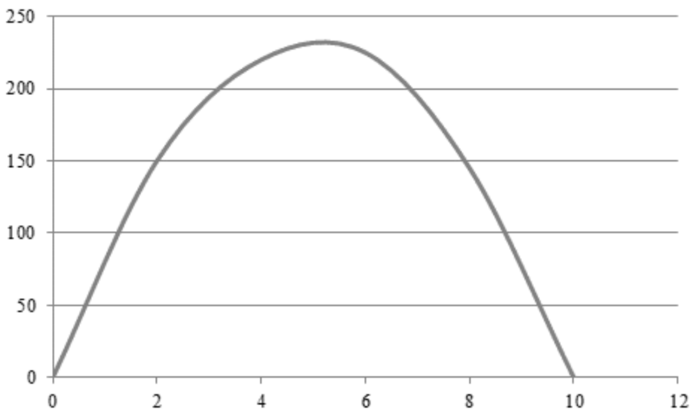

Fig. 4. Trend of power change

5. Conclusion

With the increasing attention to the use of energy, solar energy storage has become a hot research topic in recent years. Therefore, it was very important to study the energy storage and power system simulation. The results of the 50 simulation experiments showed that the results were satisfactory and the parallel effect was better in the research process of solar energy storage and power system simulation experiment. This was mainly because of the increase of the task to make the simulation process more time-consuming. When the serial threshold was 2 and 1, the efficiency was lower than the serial. At the same time, the simulation results showed that the current, light intensity and temperature of the solar system were basically the same. At the same time, the trend of power, light intensity and temperature of the roof solar system were basically the same. The power of each period of the simulation experiment can meet the requirement of the rated power. In summary, the parallel effect of serial computing power system was better. Therefore, designers can optimize the energy efficiency of rooftop solar system and power system from the point of view of simulation operation and system power in the process of the solar system and power system improvement in the future.

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