Research on Modeling and Simulation of Detailed Model of Photovoltaic Power Generation System

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Abstract: With the photovoltaic, fan and other new energy in the proportion of distribution network is growing, the photovoltaic power generation system and the process of accurate simulation is of great significance. Based on Matlab / Simulink, a detailed model of PV array, detailed model of MPPT controller and detailed model of PV inverter control strategy are established according to the actual principle of grid connection, and the process of grid connection of photovoltaic power generation system is simulated. The photovoltaic grid connected waveforms of the mixed-mode simulation system of distribution network of China Electric Power Research Institute are compared with Simulink model simulation waveforms, and the accuracy of the model is verified. The experimental results show that the detailed simulation model of photovoltaic power generation system can accurately reflect the grid connection process of photovoltaic power generation system.

1. Introduction

In recent years, with the traditional energy shortage and environmental problems become increasingly serious, and the rapid development of clean energy and distributed power generation technology, photovoltaic, fan and other new energy distributed power generation technology in the proportion of distribution network increased dramatically. Among them, the photovoltaic power generation system because of its flexible application, convenient and so on, in the distribution network has a very good application prospects. The modeling and simulation of the grid-connected process of the photovoltaic power generation system has a guiding effect on the actual photovoltaic power generation system. Therefore, it is very important to establish a realistic simulation model of PV power generation system for the development of PV power generation system.

Researchers at home and abroad have carried out some research on the modeling and simulation of photovoltaic power generation system. The photovoltaic power generation model is reviewed in [1]. Literature [2] ~ [5] carried out preliminary modeling work on PV array and MPPT. In the literature [6], the characteristics of PV arrays under different conditions were analyzed. The control strategies of the inverter are discussed in [7] ~ [10]. Among them, the control strategy of PQ, V / f and Droop is the focus of these four literatures.

2. Mathematical Model of Photovoltaic System and Simulink Model

As shown in Figure 1, the solar photovoltaic array of photovoltaic power generation system of light into DC power, the boost circuit MPPT controller, and then through the DC / AC inverter control strategy into alternating current through the filter and isolation transformer into the power grid.

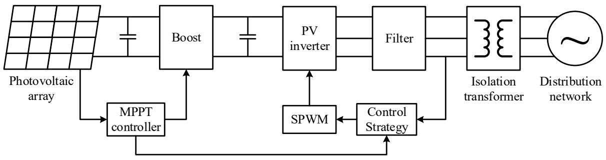

Figure 1 PV power generation structure.

The detailed Matlab / Simulink model of each part of the grid-connected model of the photovoltaic power generation system will be established in order to carry out the next step-by-step process simulation study.

2.1. Photovoltaic array mathematical model and Simulink model

2.1.1. Mathematical model of photovoltaic array

Based on the theory of electronics, photovoltaic panels are affected by light to produce photovoltaic effects, solar energy into electrical energy. The equivalent circuit diagram of the PV array is shown in the following figure:

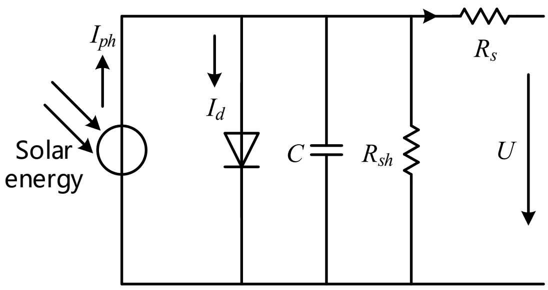

Figure 2 Photovoltaic array equivalent circuit.

In Figure 2, I_{ph} is the current generated by the photovoltaic effect, I_d is the current flowing into the diode, C is the photovoltaic array capacitance, R_{sh} is the photovoltaic parallel resistance, R_s is the photovoltaic series resistance, the photovoltaic array equation:

$$I = I_{ph} - I_d[exp\left[\frac{q(U+IR_S)}{nKT}\right] - 1] - \frac{U+IR_S}{R_{sh}} \quad (1)$$

Formula: q is charge, K is Boltzmann constant, T is temperature.

Since some of the parameters in (1) are difficult to determine, the mathematical model commonly used in the project is:

$$I = I_{sc} - C_1 I_{sc}(exp\left[\frac{U}{C_2 U_{oc}}\right] - 1) \quad (2)$$

Formula: I_{sc} is short circuit current, C_1 and C_2 are undetermined coefficient, U_{oc} is open circuit voltage.

In the maximum power point available C_1、 C_2:

$$\begin{cases} C_1 = (1 - \frac{I_m}{I_{sc}})\, exp\left[\frac{U_m}{C_2 U_{oc}}\right] \\ C_2 = \left(\frac{U_m}{U_{oc}} - 1\right)\left[\ln\left[1 - \frac{I_m}{I_{sc}}\right]\right]^{-1} \end{cases} \quad (3)$$

Formula: U_m is the maximum power point voltage, I_m is the maximum power point current.

Considering the variation of the intensity S and the temperature of the photovoltaic array T, the formula (2) becomes:

$$I = I_{sc1}\frac{S}{S_1}(1 + \alpha\Delta T)[1 - C_3(exp\left[\frac{U}{C_4 U_{oc1}\ln(e+\beta\Delta S)(1-\alpha\Delta T)}\right] - 1)] \quad (4)$$

Formula: S_1 is before the change in light intensity, I_{sc1} changes before the short-circuit current, U_{oc1} is the open circuit voltage before the change, ΔT is the PV array change temperature, the value of α is 1.2×10^{-3}, the value of β is 5×10^{-3}, C_3 and C_4 are the changes of C_1 and C_2:

$$\begin{cases} C_3 = (1 - \frac{I_{m1}}{I_{sc1}})\, exp\left[\frac{U_{m1}}{C_4 U_{oc1}}\right] \\ C_4 = \left(\frac{U_{m1}}{U_{oc1}} - 1\right)\left[\ln\left[1 - \frac{I_{m1}}{I_{sc1}}\right]\right]^{-1} \end{cases} \quad (5)$$

Formula: I_{m1} is the maximum power point current before the change, U_{m1} is the maximum power point voltage before the change.

2.1.2. Photovoltaic array Simulink model

Based on the mathematical model (2) ~ (5) of the photovoltaic array, the following photovoltaic array Simulink model can be established:

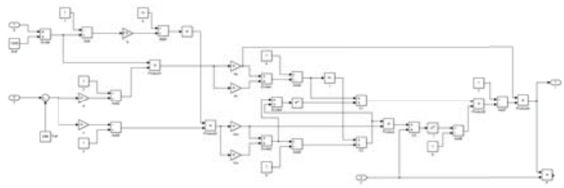

Figure 3 Photovoltaic array Simulink model.

2.2. MPPT controller algorithm and Simulink model

Photovoltaic array output P-V curve as shown below:

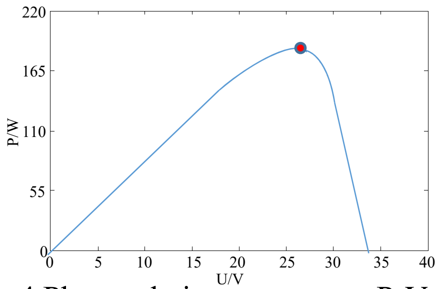

Figure 4 Photovoltaic array output P-V curve.

As can be seen in Figure 4, if you want the photovoltaic inverter in the photovoltaic power generation system to output the maximum power, the voltage needs to take the red dot position in the figure. Since the light intensity S and the photovoltaic array temperature T have a significant effect on the curve, in practice, S and T are in a state of constant change in general. Therefore, need to constantly track the maximum power point to ensure that the photovoltaic power generation system to maximize the output power.

2.2.1. MPPT controller algorithm

The maximum power MPPT controller research tracking algorithm commonly used constant voltage tracking method (Constant Voltage Tracking CVT (Perturbation), And Observation interference observation method referred to as P&O), the incremental conductance method (Incremental Con-ductance method referred to as INC), the incremental conductance method based on variable step size gradient. In this paper, the MPPT controller is designed based on the incremental conductivity method. The overall flow of the incremental conductivity algorithm is shown in the following figure:

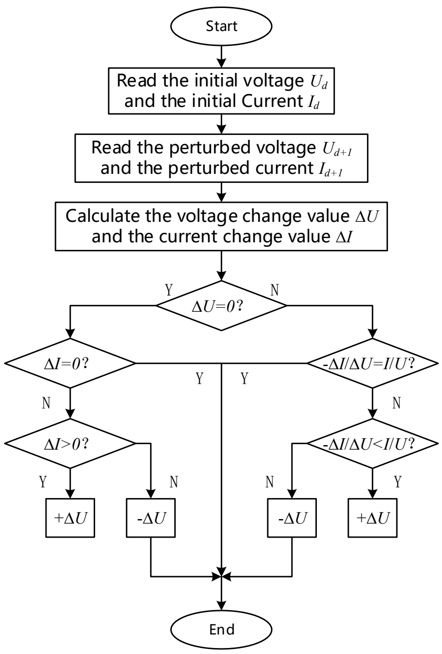

Figure 5 Incremental conductivity algorithm flow chart.

2.2.2. MPPT controller Simulink model

Based on the overall flow chart of the incremental conductivity algorithm, the following MPPT controller Simulink model can be established:

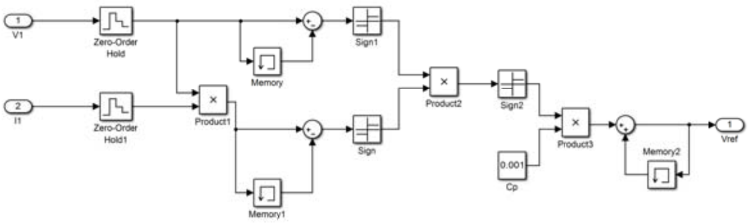

Figure 6 MPPT controller Simulink model.

2.3. Principle and Simulink Model of Photovoltaic Inverter Control Strategy

According to the research of domestic and foreign scholars, there are constant power control strategy (PQ control strategy), constant voltage constant frequency control strategy (V / f control strategy) and droop control strategy (Droop control strategy). Based on MPPT for tracking the maximum power, this paper chooses the PQ control strategy as the PV inverter control strategy.

2.3.1. PQ control strategy principle of PV inverter

The maximum power P_{ref} and Q_{ref} traced by MPPT, the PV inverter PQ control strategy based on this value, can output the ideal active power and reactive power of AC side of PV inverter.

Based on KVL law, the differential equation of photovoltaic inverter is obtained:

$$U = u_{abc} + L\frac{di_{abc}}{dt} \tag{6}$$

Formula (6) through the park transformation, can be obtained in the rotating coordinate system power calculation formula, when the AC side voltage for the standard symmetrical three-phase sine wave, u_q is zero, can be simplified power calculation formula:

$$\begin{cases} P_{\mathrm{ref}} = \frac{3}{2} u_{\mathrm{d}} i_{\mathrm{dref}} \\ Q_{\mathrm{ref}} = -\frac{3}{2} u_{\mathrm{d}} i_{\mathrm{qref}} \end{cases} \tag{7}$$

Therefore, the typical block diagram of PQ control strategy for PV inverter is shown in the following figure:

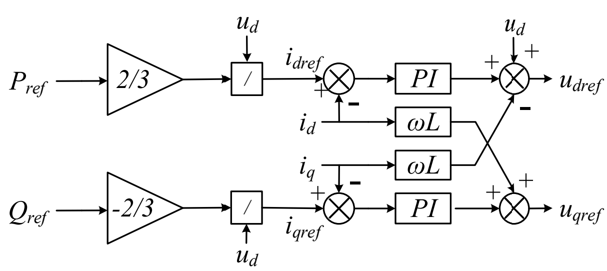

Figure 7 PQ control strategy of PV inverter typical structure block diagram.

As shown in figure 7, the PV inverter PQ control strategy converts P_{ref} and Q_{ref} measured by MPPT into current reference values i_{dref} and i_{qref} by equation (7), is adjusted by the PI regulator and sums with $i\omega L$ and u_d (u_q=0) as the voltage reference values u_{dref} and u_{qref}, and the voltage reference is modulated by SPWM, control the duty ratio of the power electronic switch of the PV inverter, and ultimately change the active power output of photovoltaic inverter ideal and reactive power.

2.3.2. PV inverter PQ control strategy Simulink model

Based on the typical structure diagram of PQ control strategy of PV inverter, the PQ control strategy of PV inverter can be established Simulink model:

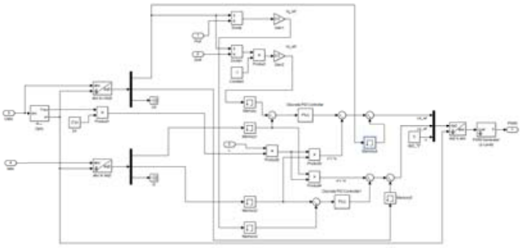

Figure 8 PQ control strategy Simulink model of PV inverter.

3. Digital analog hybrid simulation of photovoltaic power generation system

3.1. Digital analog hybrid simulation management system of distribution network of China Electric Power Research Institute

China Electric Power Research Institute of distribution network hybrid simulation management system is a real-time simulation of high-speed analog and I / O interface integration with high-performance digital simulation technology and physical equipment such as PV simulator, wind power simulator, energy storage simulator and RLC load, it can simulate a variety of equipment and off the grid, dynamic reactive power compensation process. It can be concluded that the simulation results of the digital analog hybrid simulation management system are consistent with the real results. China Electric Power Research Institute distribution network analog digital mixed simulation management system interface as shown below:

Figure 9 Distribution network digital analog hybrid simulation management system operation interface.

3.2. Digital analog hybrid simulation method for photovoltaic power generation system

The required experimental equipment is: 10kW photovoltaic power generation simulation device, 120kVA analog power grid, 120kVA isolation transformer and transformer neutral point grounding device, 50kVA distribution transformer, circuit breaker, programmable RLC load, 10Kw PVS.

Step 1: Start the analog power grid, the PV simulator, close the network topology at the PV outlet, and connect all the circuit breakers, contact cabinets and switches, and the programmable load to start the grid.

Step 2: Wiring according to the line topology, the PV through the PVS and circuit breaker into the main bus. The current and voltage are measured by current clamp and voltmeter. The current value of voltage and the low voltage side current value of the transformer are measured by measuring the voltage at the lower part of the circuit breaker and the low voltage side of the transformer. Use the oscilloscope to display the actual waveform image and waveform.

Step 3: Operate the host computer control program to achieve start PVS inverter, close the circuit breaker switch.

Step 4: operate the host computer photovoltaic power generation system device simulation software, set the light intensity.

Step 5: observe the oscilloscope, PV simulator output and lower computer equipment measurement feedback to the host computer control software photovoltaic output value.

Step 6: The oscilloscope reaches the specified time, stops recording, turns off the PV simulator, disconnects the circuit breaker, performs a phased enlargement of the recorded waveforms and copies the corresponding PNG.

4. Simulation and Analysis of Grid - connected Process in Photovoltaic Power Generation System

4.1. Photovoltaic power generation system detailed model application scenario

In the Matlab / Simulink connected to Figure 3, Figure 6, Figure 8 shows the Simulink model, and dragged into the Matlab / Simulink has been integrated RLC model, circuit breaker model, isolation transformer model, and system model, composed of photovoltaic power generation system simulation Simulink model. Photovoltaic grid connected simulation Simulink model shown in figure 10.

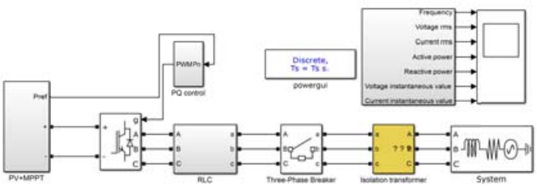

Figure 10 Photovoltaic grid connected simulation Simulink model.

Simulation of the hardware environment for the installation of MATLAB R2014a PC, which CPU clocked at 1.8GHz, 8GB memory.

4.2. Photovoltaic power generation system detailed model grid - connected process simulation results

In this paper, the circuit breaker closure time point is set to 0.4s position, PV waveform changes as shown in Figure 11:

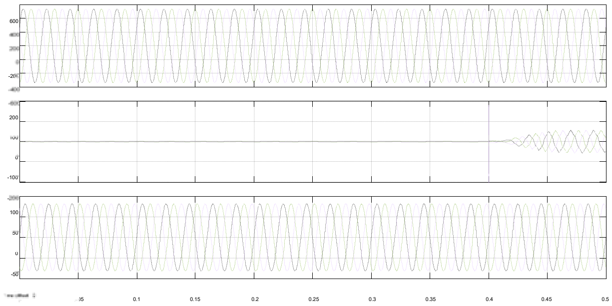

Figure 11 Different scale distribution network model converter output side active power.

It can be seen from the figure that the PV output voltage and the grid current are not changed obviously. PV photovoltaic output current has been in the vicinity of 0A with a very small shock, photovoltaic grid instantaneous photovoltaic output current in the grid instantly a significant surge, then quickly reduced to 0A near, and gradually increased to stable.

4.3. Digital analog hybrid simulation result analysis of photovoltaic grid connected process

Test time is 10 minutes, the amplitude set from top to bottom followed by ± 500V, ± 10A, ± 100A. Oscilloscope display data from top to bottom in order to express the photovoltaic output voltage A, B, C phase value, the PV output current A, B, C phase value, and the dot current A, B, C phase value.

As shown in Figure 12, the oscilloscope shows the waveform time: 28.756s to 29.256s, for the photovoltaic grid instantaneous photovoltaic output voltage and current changes in the grid.

Figure 12 Photovoltaic grid - connected instantaneous voltage and current and grid - connected current changes waveform.

It can be seen from the figure that there is no significant change in the instantaneous PV output voltage and the grid current. Photovoltaic grid-connected instantaneous PV output A-phase and B-phase current has a significant surge, then quickly converge near the PV output current 0A near, and with a very small amplitude of the shock.

As shown in Fig. 13, the oscilloscope shows the waveform time: 251.001s to 291.001s, which is the PV output voltage current and the grid current change during the PV stabilization process.

Figure 13 Photovoltaic Grid - Connected Steady Process Voltage Current and Grid - Connected Current Variation Waveform.

It can be seen from the figure that the photovoltaic output voltage and the grid current are not changed obviously, and the PV output current has obvious change process. Affected by the inverter, three-phase current amplitude in a period of time to stabilize in a smaller value, after the A-phase current amplitude in the negative half-axis has a significant fluctuation after a slight increase and stability of about 10s, and then instantaneous increase and stability of about 20s, and then gradually increased 10s after the reduction to 10s before the amplitude, and finally gradually Increase and stabilize.

4.4. Comparison of simulation results

By comparing the results of the two simulations, we can see that Simulink simulation of the photovoltaic output current stability faster, but the process and digital analog hybrid simulation results are basically the same. In addition, the simulation results of grid connected PV system are consistent with the simulation results of the digital analog hybrid simulation. Therefore, the detailed model of the photovoltaic power generation system described in this paper can accurately realize the simulation of the real process of the photovoltaic power generation system.

5. Conclusion

In this paper, Simulink modeling is carried out for the detailed model of photovoltaic power generation system, and the process of grid connection of photovoltaic power generation system is simulated. Based on the distribution network digital analog hybrid simulation management system, the digital analog hybrid simulation of the grid - connected process of the photovoltaic power generation system was carried out. By comparing the waveforms of the two simulation results, the feasibility of the detailed model of the photovoltaic power generation system described in this paper is proved.

Acknowledgements

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