Load stability analysis of Kazakhstan photovoltaic power system based on data visualization

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Abstract: Traditional methods can not track the load migration of Kazakhstan photovoltaic power system dynamically, and the analysis results have limitations. Therefore, this paper introduces the data visualization method to analyze the load stability of Kazakhstan photovoltaic power system. The simulation model of photovoltaic power system is built to set the model parameters. The system stability node is obtained by using the principle of power flow calculation. The load stability analysis of the system is realized by controlling the output impedance of boost converter. In order to verify the effectiveness of the proposed method, a comparative experiment was designed. The results show that this method can control the operation state of Kazakhstan photovoltaic power system, and has a good effect on the load stability analysis of the system.

1. Introduction

At present, photovoltaic power generation and wind power generation are the main energy forms in Kazakhstan. However, photovoltaic power system has been widely used in Kazakhstan due to its high reliability, long service life and zero pollution to the environment. For the photovoltaic power system, whether the load is stable is very important. Once the load imbalance occurs during the operation of the system, it will seriously affect the efficiency of the system. Therefore, how to effectively improve the system load stability is one of the foundations to solve the problem of system load balancing. When analyzing the static system, the traditional method is more accurate. However, when analyzing dynamic system, the system load migration will affect the accuracy of analysis results.

Therefore, based on the above analysis, this paper proposes a load stability analysis method of Kazakhstan photovoltaic power system based on data visualization.

2. Load stability analysis of Kazakhstan photovoltaic power system based on data visualization

2.1. The simulation model of Kazakhstan photovoltaic power system was established

Boost converter in Kazakhstan photovoltaic power system mainly operates in two-stage series mode. The equivalent circuit of two-stage series Boost converter in photovoltaic power system is shown in the following figure
Figure 1 Equivalent circuit of a two-stage tandem Boost converter for a photovoltaic power system

According to the principle of switching element average model method, the equivalent circuit of Boost converter in the figure above is analyzed, and the circuit equation shown below is obtained.

\[
\begin{align*}
L_1 \frac{di_{L_1}}{dt} - d_1(t)u_{c_1}(t) + u_{c_2}(t) &= V_{in} \\
i_{L_1}(t) - d_1(t)i_{L_1}(t) - C_1 \frac{du_{c_1}}{dt} &= i_{L_2}(t) \\
L_2 \frac{di_{L_2}}{dt} - d_2(t)u_{c_2}(t) + u_{c_2}(t) &= u_{c_1}(t) \\
i_{L_2}(t) - d_2(t)i_{L_2}(t) - C_2 \frac{du_{c_2}}{dt} &= \frac{u_{c_2}(t)}{R}
\end{align*}
\]

(1)

In formula (1), \(i_{L_1}\) and \(i_{L_2}\) are currents passing through inductance \(L_1\) and inductance \(L_2\) respectively; \(u_{c_1}\) and \(u_{c_2}\) respectively represent the voltage at both ends of capacitor \(C_1\) and capacitor \(C_2\) in the equivalent circuit of two-stage series Boost converter; \(C_1\) and \(C_2\) are capacitance of capacitor \(C_1\) and \(C_2\), respectively. According to the PI control principle of two-stage tandem Boost converter, the PI controller output power of Boost converter can be calculated as follows:

\[
u_{c_2}(t) = k_{p_j}(V_{reg} - u_{c_2}(t)) + k_{i_j}\int(V_{reg} - u_{c_2}(t))dt
\]

(2)

In formula (2), \(k_{p_j}\) and \(k_{i_j}\) are PI controller parameters controlling Boost converter; \(V_{reg}\) is the control input of PI controller of Boost converter; \(u_{c_2}\) is the feedback terminal voltage controlled by PI for Boost converter. According to the above calculation process, under the control of voltage mode, it can be obtained that the state variable of the two-stage series Boost converter of photovoltaic power system is \(x = [u_{c_1}(t) i_{L_1}(t) d_1(t) u_{c_2}(t) i_{L_2}(t) d_2(t)]^T\). After the photovoltaic power system simulation model is established, the system model parameters are visualized.

2.2. Visual setting of photovoltaic power system model parameters

The visualization processing of photovoltaic power system model parameters is mainly to set the equivalent system model parameters established above. Therefore, the objective function of setting the model parameters of the photovoltaic power supply system is given as follows:
\[
\begin{align*}
    k_p - j \frac{k_i}{\omega_p} &= \frac{1}{A_m G_p (j \omega_p)} \\
    k_p - j \frac{k_i}{\omega_g} &= \frac{e^{j \phi_m}}{A_m G_p (j \omega_g)}
\end{align*}
\]  

In formula (3), \( \omega_p \) is the angular frequency of the forward channel transfer function of the controller of the converter; \( \omega_g \) is the crossing angular frequency of the amplitude of the forward channel transfer function of PI controller; \( A_m \) is the target value of the amplitude margin of the model parameter setting of the photovoltaic power system; \( \phi_m \) is the target value of phase angle margin of model parameter setting; \( k_i \) is the proportion parameter. For the given target value of amplitude margin and phase angle margin, if there is a large angular frequency, the curve of target parameter can be drawn according to the above formula, then the parameters corresponding to the intersection of amplitude margin and phase angle margin curve are the parameters after visual setting of the model. After setting the model parameters, the steady-state operation point of the photovoltaic power system is obtained.

2.3. The steady-state operating point of the photovoltaic power system is obtained

Since the photovoltaic power system is controlled by DC voltage-reactive power, according to the principle of power flow calculation, the steady-state operating point can be solved in the following steps.

1. Input the known DC side voltage and plug the voltage value into the voltage calculation equation of DC side node in the photovoltaic power system as shown below to obtain the DC side current of the power system.

\[
I_{dc} = G_{dc} U_{dc}
\]  

In formula (4), \( U_{dc} \) is the known DC side voltage; \( G_{dc} \) is the equivalent parameter of the ac side of the system.

2. The load on the AC side of the system is equivalent converted to the load on the DC side to obtain the output power of the DC side of the photovoltaic power system. The output power obtained is again equivalent to the load power on the AC side. In an ideal state, the converter loss during the conversion from the DC side to the AC side is ignored.

3. Calculate the load flow of the photovoltaic power system to obtain the three-phase AC voltage of each node on the AC side. Judge whether the photovoltaic power system power flow calculation converges and set the minimum convergence value of power flow calculation. If after two power flow calculations, the difference of power and voltage is less than the set minimum convergence value, then the calculation stops, and the node at this time is the steady-state operation node. Otherwise, if the above conditions are not satisfied, return (1) to recalculate. According to the above contents, the negative impedance characteristics of the photovoltaic power system are studied to complete the analysis of the load stability of the system.

2.4. The load stability analysis of photovoltaic power system is realized

According to the control form of photovoltaic power system, the ratio between the output impedance of the Boost converter at the previous stage and the input impedance of the Boost converter at the next stage is coupled with the voltage loop of the converter at the previous stage without considering the disturbance of input voltage and output current. The ratio is negative feedback factor, which will affect the loop gain of the system.

The reference voltage factor of the superior converter is \( G_1 \). If the poles of \( G_1 \) are in the left half plane, the output voltage of the upper stage is stable. At this point, if the reference voltage factor of the
The next stage converter is G2, all poles are also located in the left half plane, then the output voltage of the system's next stage load converter is stable. Therefore, when the photovoltaic power supply system is under open-loop control, the load stability of the system is mainly determined by the impedance ratio between the two stages of the converter. When the extreme values of factors G1 and G2 are in the left half plane, the load of the system is stable. In the closed-loop control of the system, all the extreme values of the reference factor G2 satisfying the superior converter are at the zero point of the left half plane, and the system load is stable.

3. Empirical test research

3.1. Experimental process
The detailed physical model of PV power system was built by Simulink simulation tool, and different system operating load parameters were set. Stability analysis methods of experimental group and contrast group were used to analyze the operation stability of photovoltaic power system under different load conditions. The concept of stability index is introduced as one of the comparison indexes in this experiment, and the performance of the stability analysis method is compared by comparing the convergent speed of photovoltaic power system operation. Another comparison index of this experiment is the time delay change of photovoltaic power system after applying two stability analysis methods. By comparing the time delay of photovoltaic power system, the effectiveness of the load stability analysis method is measured.

Process the test data on the two experimental comparison indexes, analyze the experimental data and get the final experimental conclusion.

3.2. Experimental results
The parameters of the simulated photovoltaic power system established in Simulink were changed, and 10 groups of tests were carried out. In Simulink, after applying the load stability analysis method of the experimental group and the contrast group, the comparison results of the convergence speed of photovoltaic power system operation are shown in the following table.

| Serial number | Experimental group method | Comparison group method |
|---------------|---------------------------|------------------------|
| 1             | 53.7                      | 30.9                   |
| 2             | 59.8                      | 10.7                   |
| 3             | 74.1                      | 29.7                   |
| 4             | 56.7                      | 22.7                   |
| 5             | 58.2                      | 28.5                   |
| 6             | 58.6                      | 22.3                   |
| 7             | 55.7                      | 14.5                   |
| 8             | 61.3                      | 22.3                   |
| 9             | 68.8                      | 13.3                   |
| 10            | 54.6                      | 27.5                   |

It can be seen from the above table that, after applying the stability analysis methods of the experimental group and the contrast group respectively, the convergent speed of the photovoltaic power system established in Simulink is different. With the same power system parameters, the convergence rate of the photovoltaic power system in the experimental group was faster than that in the contrast group. When the same stability analysis method is applied to different photovoltaic power system parameters, the convergence rate of the experimental group method is basically unchanged, while that of the contrast group method varies greatly. The above results indicate that the controller of the experimental photovoltaic power system established in Simulink can achieve faster convergence rate and higher load stability during system operation after applying the load stability analysis method of the experimental group.
When comparing the above experimental indexes in Simulink, the photovoltaic power system with a group of known parameters is randomly selected to synchronously test the change of the power system's delay under different load stability methods. The system with the two stability analysis methods is compared with the original power system without the load stability analysis method. The comparison results are shown in the figure below. The information in the diagram is analyzed and the experimental conclusions are drawn.

According to the analysis of the curve in the figure above, the stability analysis method based on data visualization and the traditional method can reduce the load current variation of photovoltaic power system. But the stability of power system stability analysis method based on data visualization is obviously better. This shows that the load stability analysis method proposed in this paper can reduce the load current variation amplitude more effectively.

To sum up, the load stability analysis method of Kazakhstan photovoltaic power system based on data visualization studied in this paper has very good practicability and effectiveness.

4. Conclusion
During the operation of the photovoltaic power system, the demand side power consumption is in dynamic change all the time, so the load of the power system needs to be in dynamic balance all the time. However, once the load of the system changes, the load balance of the photovoltaic power system is prone to unstable oscillation, which will seriously affect the working efficiency of the system. Therefore, this paper proposes a load stability analysis method of Kazakhstan photovoltaic power system based on data visualization, and verifies the effectiveness and practicability of this method through comparison experiments with traditional methods.

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