Solution to Photovoltaic Power Station’s Islanding Operation

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Abstract: When disconnected from the power system grid, the steadily working photovoltaic power plants would get into the state of islanding operation. Photovoltaic inverter has the function of preventing islanding operation, and state of art inverter designing all contained such components. However, when a photovoltaic power station was at large scale with numerous photovoltaic inverters, inverters would not perform the desired effect. This the paper proposed a novel detection method, which could effectively prevent islanding operation. The detection method used the characteristics of islanding operation to test whether a photovoltaic power station encounters such state. Experiments showed that the proposed method being accurate and fast, capable of preventing islanding operation of photovoltaic power station.

1. Introduction

Photovoltaic power station was composed of photovoltaic panels, inverter, box-type transformer and cable. Photovoltaic panels generated electricity through inverter into alternating current, and then connected to 35kV bus bar by boosted to 35kV ac, Finally, the main transformer was pumped up to 110kV into the main network of the system. The system structure is shown in figure 1.

Fig.1 Electrical wiring diagram of Photovoltaic power station

When the photovoltaic power station is separated from the main network of the power system, the voltage output is maintained, the photovoltaic power station would turn into the isolated island operation state [1-3]. “The Technical regulations on photovoltaic power station access to power grid” which was settled by The State Grid corporation (Q/GDW617-2011) 8.2.2 and the standard rate of "code for design of photovoltaic power stations" (GB 50797-2012) 9.3.4 established, photovoltaic power stations would not have isolated island protection, for a large photovoltaic power station, the relay protection device of the public power grid must ensure that the photovoltaic power station is removed when the public power grid fails. The PV inverter manufacturers used in large photovoltaic power stations all promised that the inverter can effectively prevent the occurrence of isolated island operation [4][5].

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The paper was based on the characteristics of the actual power capacity from the single island photovoltaic power station operating. The method could effectively prevent the isolated operation of large photovoltaic power station, which had strong practicality.

2. Operation status and hazards of the photovoltaic power station isolated island

The operation of a photovoltaic power station on a single island refers to the situation that when the photovoltaic power station was disconnected from the main network of the power system, the photovoltaic modules still continued to provide power for regional power equipment, what was a common problem in photovoltaic power stations.

The main hazards of the photovoltaic power station wear as follows:
1) Because of the high voltage, it was harmful to the personal safety of the staff;
2) Due to the abnormal voltage and frequency, the equipment on the 35kV bus line was damaged;
3) When the power supply of the photovoltaic power station was restored, the unsynchronized voltage phase would cause the generation of surge current, which would cause the photovoltaic power station to disconnect from the grid system again and to trip again;
4) the operation of isolated island would affect the correct operating of breaker;

3. The Detection method of isolated island operation of photovoltaic power station

At present, there were mainly passive detection methods and active detection methods for the operation of photovoltaic power stations on isolated islands.

3.1 Passive detection method

Passive detection method was to detect the voltage, frequency, phase and harmonic changes at the output end of the PV inverter when the system of photovoltaic power station and the basic system to determine whether the photovoltaic power station into the island running state.

3.2 Active detection method

The active detection method was to control the power, frequency and phase by the photovoltaic inverter. In normal operation, these disturbances cannot be detected due to the balance of the main network. When the isolated island occurred, the disturbance output by the PV inverter would exceed the normal allowable range, so as to detect the operation.

3.3 The limitations of existing detection methods

In fact, large photovoltaic power station on 35 kV bus usually accessed multiple inverters branch, the inverter's own detection wouldn’t detect the island operation because of the interaction between each inverter branch. When a large photovoltaic power station was disconnected from the main network, it was easy to run on a single island.

At this stage, many large photovoltaic power stations still ran on isolated islands After disconnected from the main network. Figure 2 showed the variation of 35kV bus waveform recorded by fault recorded device while the operation in Gansu.
4. Modelling and Simulation

4.1 Equivalent Circuit

Because the photovoltaic inverter branches were connected with each other, it was not accurate to judge the operation of isolated islands by a single photovoltaic inverter. In order to solve the problem of isolated operation, it was necessary to take large photovoltaic power station as the research object. When a large photovoltaic power station was running on a single island, each inverter branch continued to output power, charging each other back and forth through the 35kV bus. The equivalent circuit of a single island was shown in figure 3.

![Fig.3 Equivalent circuit diagram of Islanding operation](image)

The equivalent circuit according to figure 3, the inverter output of photovoltaic power station was a stable current source, its single-phase current was:

\[ I = I_m \sin(\omega t + \phi) \]

where \( I_m \) was the peak current of inverter, \( \omega = 2\pi f \), \( f = 50Hz \) is the frequency; \( \phi \) is the phase angle;

The single-phase voltage was: \( U = IZ \) ; Where: impedance \( Z = R + jX \), \( R \) is resistance (negligible), \( X \) is reactance;

\[ X = X_L - X_C \] ; Where: impedance \( X_L = 2\pi fL \), Capacitive reactance \( X_C = 1/2\pi fC \), \( L \) was inductance, \( C \) was capacitance.

4.2 Instance Modeling

Simulate the operation state of a large photovoltaic power station in Gansu province in fig.2, table 1 and table 2 showed the original parameters of each photovoltaic inverter branch cable.

| Cable outlet | Line1 | Line2 | Line3 | Line4 | Line5 | Line6 | Line7 | Line8 |
|-------------|------|------|------|------|------|------|------|------|
| length/m    | 1.435| 1.945| 2.485| 1.125| 2.215| 1.68 | 1.145| 0.61 |
Tab.2 Parameter of Cable ZRC-YJV22-26/35kV

| Cable gas capacity | Section parameter of 50mm² | Section parameter of 70mm² |
|--------------------|-----------------------------|-----------------------------|
| Inductance L       | 0.5263μH/m                  | 0.5031μH/m                  |
| Capacitive C       | 122pF/m                     | 135pF/m                     |

Table 3 showed the original parameters of each photovoltaic inverter branch.

Tab.3 Transformer parameter

| Name           | Cases of variable volume | The rated voltage | Short circuit impedance |
|----------------|--------------------------|-------------------|-------------------------|
| Parameters     |                          | 1250kVA           | 38.5kV                  |
|                |                          |                   | 5.72%                   |

The inductance and capacitance of each branch were calculated according to the parameters in table 1 and table 2. The parameters are shown in table 4:

Tab.4 Cable parameter

| Cable outlet | Line1 | Line2 | Line3 | Line4 | Line5 | Line6 | Line7 | Line8 |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Inductance L/μH | 731.9 | 988.5 | 1260.2| 316.5 | 586.1 | 855.2 | 1124.3 | 581.6 |
| Capacitive C/pF | 188136| 256985| 329885| 143100| 293435| 221210| 148985| 76955 |

According to the inductance and capacitance values of each outlet in table 4, the inductance and capacitance of each outlet line could be calculated. The value was shown in table 5:

Tab.5 Impedance of Cable

| Cable outlet | Line1 | Line2 | Line3 | Line4 | Line5 | Line6 | Line7 | Line8 |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Impedance /Ω | 0.2299| 0.3105| 0.3959| 0.0994| 0.1841| 0.2687| 0.3532| 0.1827|
| Capacitive reactance /Ω | 16919.1| 12386.3| 9649.12| 22243.8| 10847.7| 14389.4| 21365.2| 41363.1|

According to the inductance and capacitance values of each branch, the equivalent impedance of box transformer could be obtained, the equivalent impedance was 117.46Ω.

By superimposing the inductance of the cable in table 5 and the inductance, the equivalent inductance of each branch can be obtained. The value was shown in table6:

Tab.6 Impedance of Cable

| Cable outlet | Line1 | Line2 | Line3 | Line4 | Line5 | Line6 | Line7 | Line8 |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Impedance /Ω | 0.9082| 0.9888| 1.0742| 0.7777| 0.8624| 0.9470| 1.0318| 0.8610|
| Capacitive reactance /Ω | 939.84| 704.88| 704.88| 704.88| 704.88| 704.88| 704.88| 704.88|

According to the specific situation that the photovoltaic power station was running on a single island, we could find that The power flow of outgoing lines 1, 3, 4, 5 and 7 being the same, and being the opposite of outgoing lines 2, 6, 8. Being equivalent in accordance with figure 3, we could obtain the capacitive and impedance of equivalent line 1 and equivalent line 2. The value was shown in table 7:

Tab.7 Line parameter

| The equivalent circuit | impedance /Ω | Capacitive reactance /Ω |
|------------------------|--------------|-------------------------|
| Line 1                 | 1148.40      | 81024.9                 |
| Line 2                 | 234.96       | 68138.8                 |

Calculated the inductive reactive power and capacitive reactive power of equivalent circuit 1 and equivalent circuit 2 respectively, The value was shown in table 8:
Tab. 8 Reactive power of Line

| The equivalent circuit | The perceptual reactive /kVar | Capacitive reactive /kVar |
|------------------------|-------------------------------|---------------------------|
| Line 1                 | 270                           | 26.17                     |
| Line 2                 | 480                           | 31.14                     |

4.3 The simulation waveform

Build a modeled by MATLAB, enter the line parameters in tables 8 and 9 into the model, and then simulate the box variable current, box variable voltage and 35kV bus voltage to obtain the simulation waveform, the waveform were shown in figures 4 and 5.

4.4 Simulation waveform analysis

1) The fault waveform recorded by the fault recorder device of the actual station during the operation of the isolated island was compared with the MATLAB simulation waveform, the variation trend of voltage and frequency on the 35kV bus were consistent.

2) The voltage and frequency of 35kV bus were increased, the voltage waveform would distort, the harmonic component increased sharply and periodic oscillation presented.

5. Governance approach

According to the fault recording, it can be seen that the isolated island protection function of the PV inverter cannot play its due role when a large photovoltaic power station is running on a single island. In view of the voltage and frequency increased of 35kV bus, the paper presented an effective method to prevent the photovoltaic power station from isolated island operation.

5.1 Analysis of electrical characteristic

According to the fault recording device fault waveform and MATLAB simulation waveform, it could be seen that the amounts of electricity on the 35kV bus of the photovoltaic power station have the following common characteristics when operating on an isolated island:

1) The voltage $U$ was raised to 1.7-2.0 times than the voltage $U_e$ during normal operation;
2) The frequency $f$ went up to about 62Hz; 3) Electrical over-excitation $K_{GJ}=(U/f)/(U_e/f_e)$;

Where: $U$ was the voltage when operating in islands, $U_e$ was the voltage of normal operation, $f$ was the frequency of the island operation, $f_e$ was the frequency of normal operation.

By calculating, it could be obtained that the over-excitation multiple was about 1.3-1.4.

5.2 Governance method

According to the voltage and frequency variation of 35kV bus line and the over-excitation multiple of the photovoltaic power station during the operation of the isolated island, the paper proposed the governance method which contained the following criteria:

1) Determine whether the PV power plant was separated from the main grid of the system;
2) The voltage of 35kV bus was greater than or equal to 130%, ie $f \geq 50.2Hz$;
3) The frequency of 35kV bus exceeded 0.2Hz during normal operation, ie $f \geq 50.2Hz$;
4) The over excitation multiple of 35kV bus was greater or equal to 1.1, ie $K_{GJ} \geq 1.1$. 
The discriminate logic of whether or not the photovoltaic power station had islanded operation was shown in Figure 6.

![Fig.6 Discriminate logic of islanding operation](image)

When a large photovoltaic power station was identified for isolated island operation, timely it would remove 35kV feeder or inverter power supply to ensure the safety of all electrical equipment and operators in the photovoltaic power station.

6. Conclusion

1) According to the voltage waveform of 35kV bus recorded by the fault recorder device of the isolated island, the islanding phenomenon would still appear when the inverter of the large photovoltaic power station ran with normal anti-islanding protection function;

2) According to the 35kV bus voltage waveform recorded by the fault recording device and the 35kV bus voltage waveform obtained by MATLAB simulation, it could obtain the situation of voltage, frequency and over-excitation multiple of 35kV bus bar when island power generation occurred.

3) The paper presented an effective method to prevent the occurrence of island operation.

References

[1] United States Patent, Method and Apparatus for Measuring the Impedance of an Electrical Energy Supply System. 2005, 8(23):131-138.

[2] Zhan jie, zhang yan etal. Analysis for Islanding of large-scale photovoltaic power Station Operation[J]. Proceeding of the CSU-EPSA, 2011,2(23):76-80.

[3] Georg, Hatz N, etal. Operation of a prototype micro grid system based on microsources equipped with fast-acting power electronics interfaces [C]. IEEE, 2004:2521-2526.

[4] Prabha, John. Definition and classification of power system stabilitys[J]. IEEE Transaction on Power Systems, 2004,19(2):1387-1401.