Test System Design of Low Voltage Ride Through of High Altitude Photovoltaic Power Station

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***Abstract*—the photovoltaic resources are abundant in the high altitude area of northwest China, but the network frame is weak in this kind of area, and it is urgent to carry out the detection of Photovoltaic grid connected network test. It is necessary to solve the problem of system insulation safety with Low Voltage Ride Through (LVRT) test for photovoltaic power generation system at high altitude area. In this paper, the principle of LVRT test system of photovoltaic power generation is analyzed. The factors affecting transient overvoltage of the system are analyzed also. According to a 35 kV LVRT experiment, the simulation calculation is studied by using ATP, sums up the test point 0.1μF grid connected capacitance and resistance of 100Ω can effectively reduce the peak of the transient overvoltage, determine the effective measures for overvoltage suppression of test process.**

***Index Terms*—Low Voltage Ride Through (LVRT), Transient Over-Voltage, Shunt Capacitor, Design of High Altitude**

I. REQUIREMENTS OF HIGH ALTITUDE LVRT TEST SYSTEM

IN July 2015, a short circuit fault occurred in a 220kV line of the state grid Tibet power company, which caused a temporary drop in voltage. Protection device uses 40 milliseconds to resect failure and the reclosing is successful, but the power of the photovoltaic power station in the Tibet power grid fluctuates greatly during the failure period. Power of some photovoltaic power stations have a sudden drop, and the total power of photovoltaic is reduced to 44%. The relevant national standards have put forward specific requirements for the Low Voltage Ride Through of the grid-connected photovoltaic power generation system [1], but Tibet is affected by the special climate and environment of high altitude [2],[3], and the original photovoltaic testing equipment can not satisfy the test requirements [4], [5]. Unable to conduct on-site testing. Tibet power grid in urgent need test system of Low Voltage Ride Through for High Altitude Photovoltaic Power Station.

II. THE PRINCIPLE OF LVRT TEST SYSTEM FOR HIGH ALTITUDE

The LVRT test standard requires using impedance to simulate the voltage drop for the power grid. By adjusting the impedance parameters, different voltage drops can be obtained. The main circuit of LVRT test system is shown in Fig 1. When CB1 and CB2 are in a closed state, closing the CB3 will produce voltage drop on the test point. LVRT test requires different voltage drop depth. Therefore, it is necessary to design impedance with multiple taps. The multi - tap reactor is usually used to simulate different impedance in the power grid. When CB3 is operated, a large transient overvoltage will be generated, overvoltage is harmful to the insulation of the test system at high altitude. So, the most important thing to development and design of a high altitude LVRT test system is reducing transient overvoltage and oscillation frequency.

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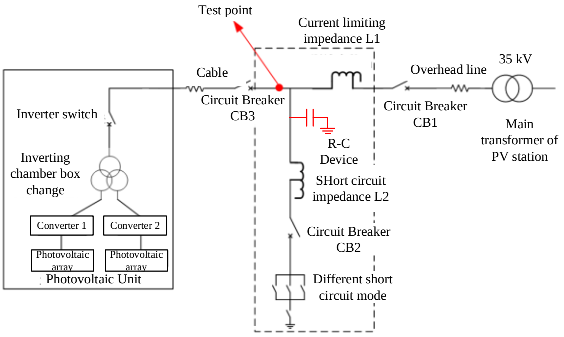


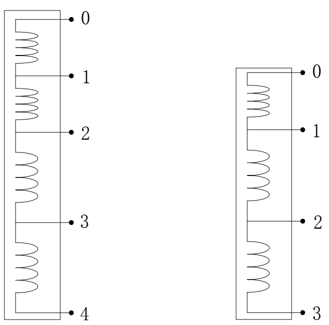
Fig.1. Device Wiring Diagram of 35 kV LVRT

According to the LVRT test system should achieving voltage drop range 0-90% of power grid, but can't affect the normal grid. So the current limiting reactor with short circuit reactor should be configured according to certain constraint, must be meet the following requirements: 1) When current limiting reactor was inputting, the voltage reduction caused by the current limiting reactor must be within 10%, to ensure the inverters of photovoltaic can be operation normally; 2) the short circuit capacity of the LVRT test system must be more than 3 times of the capacity of the measured inverter. It is required by the test standard [1]; 3) the short circuit capacity of the system should be less than 20MW, for reducing the impact of the test process on the main transformer of the photovoltaic power station.

III. TEST SYSTEM DESIGN OF LVRT

According to these principles, the short circuit reactor and the current limiting reactor was designed for multiple taps, inputting different taps to realize a variety of combination of short circuit reactor and the current limiting reactor. Optimizing reactor inductance parameters, there were four taps of short circuit reactor and five taps of current limiting reactor was designed, as shown in the Fig.2.

Optimizing inductance parameter of reactor, main parameters of reactor for LVRT device was designed, as show in TABLE.1.



(a) current limiting reactor L1 (b) short circuit reactor L2
Fig.2 multiple tap reactor

TABLE.1.
Design of Reactor main parameters in LVRT device

reactor	0 – 1	0 – 2	0 – 3	0 – 4
L_1 inductance	40mH	125mH	200mH	/
L_2 inductance	220mH	300mH	400mH	480mH

According to table 1, All possible of the power grid voltage drop depth can be calculated. Voltage drop of the LVRT test system is fully covered by inputting different reactor taps, which can satisfy the demands of all kinds of drop depth accuracy, see point of voltage drop curve Fig 3.

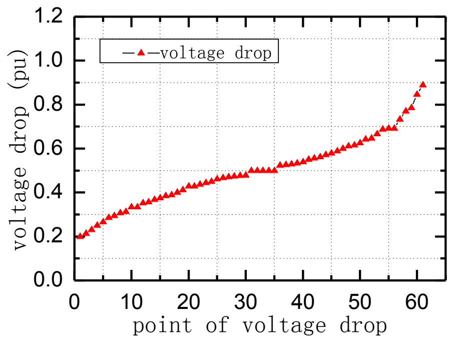


FIG. 3 Voltage drop of the LVRT test system of 35kV Photovoltaic Power Station

IV. OVER VOLTAGE ANALYSIS AND SUPPRESSION IN LVRT TEST PROCESS

Because of the high arc cutting capability of the vacuum circuit breaker, during the transient process when vacuum circuit breakers cut out current in the reactor, If the current is cut off before zero crossing, the electromagnetic energy stored in the reactor and the equivalent capacitance on the experimental loop will generate high frequency oscillation in the capacitance inductor circuit, resulting in a transient interception over voltage, which is shown in Fig. 4.

Among them, e_s is equivalent to AC power source, L is reactor equivalent, C is reactor winding and test loop of equivalent capacitance, CB is vacuum circuit breaker, u_0 is the initial voltage of capacitor, u_p is transient over-voltage of reactor on the truncated moment on current, I_{CH} is instantaneous current of reactor current before zero on the truncated moment[6-8].

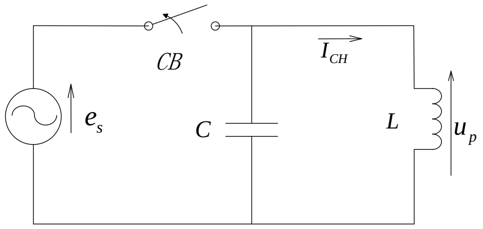


Fig.4 Equivalent-circuit Diagram That Vacuum Circuit Breakers Switch off Shunt Reactors

The electrical energy of the capacitor generates an attenuation oscillation through the inductance and circuit resistance. After the current is truncated before zero crossing, the magnetic energy on the reactor is immediately converted to the electric energy on the capacitor, as follows:

$$\frac{1}{2}LI_{CH}^2+\frac{1}{2}Cu_0^2=\frac{1}{2}Cu_p^2 \quad (1)$$

According to the previous analysis, Test System of Low Voltage Ride Through is used to adjust the reactance value of the input in the circuit by changing the connection tap of the reactor. If get larger the reactance in the experimental system, the transient overvoltage larger is generated in the process of the vacuum circuit breaker. So, when the reactor L1 uses 0 and 4 tap access system and L2 selects 0 and 3 tap access system. So that the maximum inductance value is invested in the test system. In the experimental process, the transient overvoltage amplitude of the shunt reactor of the vacuum circuit breaker is maximized. Simulation analysis is carried out for the most severe transient overvoltage. The simulation test point transient overvoltage is up to 93.39kV. The transient overvoltage curve is shown in Fig. 5.

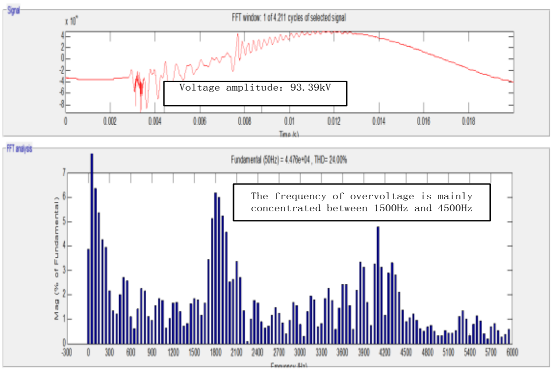


Fig.5. Transient over-voltage curve on test point

Transient overvoltage has reached nearly level of 100kV, the test system insulation will pose a risk. The frequency of overvoltage reaching 1500Hz can also cause a very large impact on the interterm insulation of the reactor. The most effective measure to restrain the amplitude and frequency of overvoltage is to install a resistance and capacitance absorption device (R-C device). The R-C device is composed of resistance and capacitance. Capacitors store and release energy through voltage changes, limiting the maximum working current of AC lines and suppressing voltage mutations on lines. Under the condition of the load is constant, the capacitance determines the voltage of the load can be, have the effect of pressure limiting, whereas resistor capacitor stored energy consumption, make line voltage high frequency oscillation process of decay, shorten the transition process, so as to reduce the over voltage.

Transient overvoltage and oscillation frequency are related to circuit resistance and capacitance（R-C）. It is a very important thing to optimum design of R-C parameters for design LVRT Test System.

V. Optimum Design of R-C Parameters for LVRT Test System

Because the amplitude and frequency of overvoltage are closely related to R-C, in particular is capacitance, but it is too large, will cause large shock current. Therefore, on the basis of 35 kV photovoltaic power station LVRT parameter testing system as an example, the simulation calculation is studied by using ATP. And the capacitance value of R-C device selection, respectively, in 0.01 μF is 0.5 μF nine sets of data, this paper compares and analyzes resistance capacity device capacitance on the transient overvoltage and inrush current relationship is shown in Fig.6. When the capacitance value increased from 0.01 with μF to 0.1 with μF, the overvoltage amplitude decreased significantly, and the area was flat at 0.2 μF. With the increase of capacitance, but elected by capacitance value of 0.2 μF to 0.5 μF can be seen in Fig.6 , although the overvoltage amplitude decreased, but the flow resistance capacity to absorb increases gradually, considering flow problem, too big to capacitor and resistor fever 0.1 μF capacitance value selection, the inrush current value is less than 50 A.

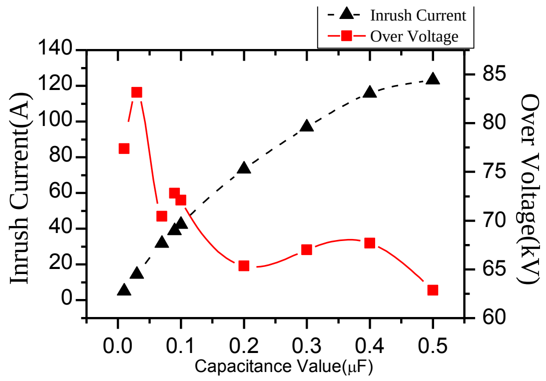


Fig.6. Effect on transient over-voltage from capacitance

R-C device selection capacitance value as 0.1 μF, resistance were selected for 10 Ω ~500 Ω interval nine sets of data were analyzed. A curve tracing of different line voltage values corresponding to the nine sets of resistance values are presented. By the Fig 7, you can see that the resistance value by 30 Ω rose to 100 Ω in the process of overvoltage amplitude decreased rapidly, and increased to 100Ω, overvoltage becomes slow, and the more the resistance caused by the line loss, the greater the resistance heating, so the resistance selection should not be too big, should be selected 100 Ω.

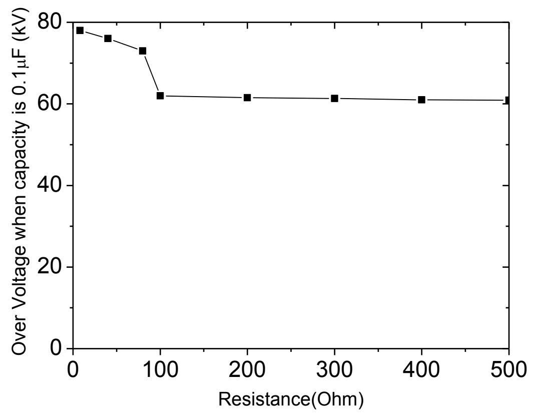


Fig.7. Effect on transient over-voltage from resistance in device

According to R-C parameters, the resistance capacity device is designed and installed at the position shown in Fig 1. And after the completion of R-C installation, overvoltage of LVRT was calculated by simulation analysis, as shown in the Fig.8.

After adding R-C devices, when two reactor for maximum input reactance, transient overvoltage simulation for test point reduce to 57.76 kV, frequency reduced to 517 ~ 550 Hz, transient over-voltage curve and amplitude frequency characteristic curve as shown in Fig 8. With the addition of resistance capacitance type overvoltage suppressor device, the transient overvoltage on each tap of the internal reactor of the low penetration device is effectively suppressed before installation.

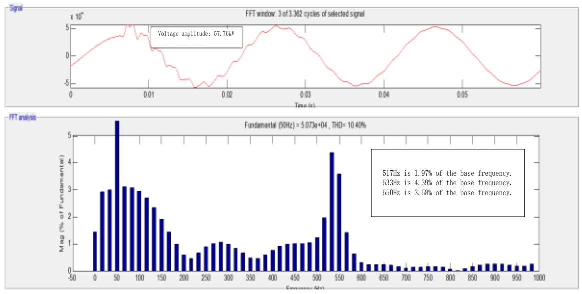


Fig.8. Transient over-voltage curve and amplitude-frequency characteristic curve on test point

VI. FIELD TESTING OF LVRT IN HIGH ALTITUDES

Through the above design and analysis, developed a high altitude photovoltaic LVRT test system and in the northwest area. It has carried out more than 50 photovoltaic power station test, no insulation and discharge problem occurred. Fig.9 shows the photovoltaic grid connected test site in yambajan, Tibet (4,300 meters above sea level).

Fig. 9 Test of yambajan Photovoltaic Power Station in Tibet

Fig.10 and Fig.11 are the overvoltage measured curves of LVRT test system after the overvoltage suppressor device is installed or not respectively. The transient overvoltage amplitude are 79.9kV and 51.8 kV respectively. The vibration frequency also changed significantly compared with that before the installation of R-C device. Comparing Figure 5 with Figure 10, when the R-C device is not installed, the simulation calculation of overvoltage amplitude and oscillation frequency are close to the measured. The overvoltage are 93.94kV and 79.9kV, respectively, and the oscillation frequency is also very high. After installing the R-C device, the comparison Figure 8 and Figure 11, the simulation calculation and the measured overvoltage are 57.76kV and 51.8kV respectively, the oscillation frequency is significantly reduced. The simulation analysis results are relatively similar, which also proves the accuracy of the simulation model.

The LVRT test system of the high altitude photovoltaic power station has been developed in many field tests in xigaze, yambajan and other places in Tibet, and the equipment is running well. The reactor parameter of testing system design is reasonable, it is achieved 0-90% different range test of Low voltage ride through. R-C device reduces the over voltage amplitude and frequency, test system of LVRT to be ensured the safety in the insulation of the high altitude.

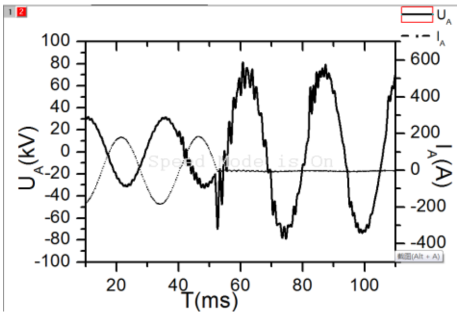


Fig.10. the measured curve of transient overvoltage without resistance capacitance device

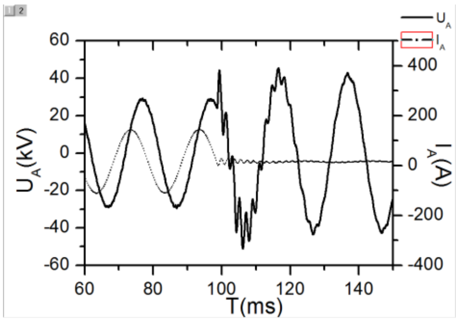


Fig.11. the measured curve of transient overvoltage with resistance capacitance device

VII. CONCIUSION

This article is described 35 kV photovoltaic (PV) LVRT test system used in high altitude environment. The principle of LVRT test system of photovoltaic power generation is analyzed. The factors affecting transient overvoltage of the system are analyzed also. The conclusions are as following:

(1) Photovoltaic power station LVRT test system inside the transient overvoltage was caused by vacuum circuit breaker cutting down reactor current. The size of the overvoltage amplitude is mainly composed of vacuum circuit breaker current closure value;

(2) The simulation calculation is studied by using ATP. Analyze and draw a conclusion that the test point 0.1μF grid connected capacitance and resistance of 100Ω can effectively reduce the peak of the transient overvoltage.

(3) Field measured data of LVRT test system in High Altitudes verifying the accuracy of overvoltage calculation model, R-C parameter selection and also the feasibility of design scheme.

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