Design and Development of the High Voltage Capacitor Step-down Power-taking Device

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Abstract: The designed device uses high voltage capacitor in series with a voltage transformer to take power. It uses the capacitance voltage resistance and the transforming characteristics of voltage transformer, and the monitoring system is supplied with power by subsequent rectifier filtering and switching circuit. As high voltage capacitor step-down has the problem of limited energy, the set of device uses voltage transformer to increase power output, and the required power are provided to the load end on the basis of the changing of the load end power, and through the relay’s on or off to control the connection or disconnection of the front-end resistance. 10kv voltage transformer are used for 110kv line, and the primary side voltage of the voltage transformer is controlled at 10kV by using the voltage stabilizing function of the rear-connected circuit. Through The overall test of power output is stable, the device operates well. can provide stable and effective low-voltage power supply for the on-line detection device of 110kV high-voltage multiple circuit.

1. Introduction

With the innovation of power grid technology, the requirements for online monitoring of electric equipment are getting higher and higher, which directly leads to higher requirements for power supply of online monitoring equipment. In terms of high-voltage transmission line monitoring, due to geographical or insulation conditions, the power supply cannot directly draws power from the low-voltage side. At present, the commonly used power supply methods are as follows: solar power supply[3-4], laser power supply, current transformer power supply[5-10] etc. Although the power source of solar power and laser power supply are taken from outside the power grid thus not being affected by the power grid, the photoelectric conversion efficiency is quite low and the cost is high, so they cannot be universally used at present. It is difficult to transmit the electric energy obtained by the current absorbed by the current transformer of the line to the tower. There are two technical difficulties in this method: (1) When the current amplitude does not reach a certain value, the predetermined power cannot be provided, which affects the normal operation of online monitoring equipment; (2) When the current increases to more than a few thousand amperes, the high voltage spikes generated by the power transformer will cause interference and damage to auxiliary equipment.

This article uses high-voltage capacitors to store electrical energy for voltage reduction and uses the voltage transformer to change voltage, thus entering the voltage stabilization circuit. By controlling the opening and closing of the circuit breaker through the voltage comparison circuit according to the required power of the back-end power supply equipment, the front resistance will be connected to or exit the system, and pass the required power to subsequent circuits to ensure that the device can run stably for a long time under low power consumption.
2. Operation Principle

Traditional capacitive power taking devices generally use capacitor divider of the capacitive voltage transformers to reduce the voltage of the electric energy transmitted on the overhead line and then transmit it to the subsequent circuit. After the over-current and over-voltage protection, the rectifier and voltage stabilization can be carried out to finally generate the electric energy available for the online monitoring device. The overall efficiency of this kind of energy taking circuit is low, and the voltage changes and the fluctuation range after rectification is large, which also cannot provide stable power. The new high-voltage capacitor power taking device proposed in this paper can solve the above problems, as shown in figure 1.

![Fig 1 Block diagram of the electrical pickup device](image)

As can be seen from figure 1 above, the high-voltage capacitor is in parallel with the overhang insulator, and the high-voltage capacitor is connected with the thermal detonator disconnector to prevent the insulator from flashover. The voltage transformer is connected in parallel with the lightning arrester and air gap on the side of the primary winding to provide double protection for the lightning strike high-current line. The voltage regulator module controls the voltage fluctuation deviation of the secondary winding of the voltage transformer, thus restricting the voltage amplitude of the primary winding to fluctuate within a small range. The voltage control comparator controls the access and disconnection of the front resistor to adjust the power of the subsequent circuit.

3. Design of power taking devices

3.1 High voltage capacitor design

The high voltage capacitor consists of several cylindrical thin film capacitors with high dc voltage resistance in series. The Ac voltage resistance of the capacitor bank in series meets the requirements of line insulation coordination. The series capacitor bank is wrapped with insulating tape and molded by silicon rubber, and the two electrodes of capacitor are drawn out by pin and box threads respectively.

3.1.1 Confirmation of voltage resistance and size

With reference to the over-voltage and insulation coordination specification, the high-voltage capacitor shall pass the test of allowable voltage tolerance under dc, Ac and lightning over voltage.

The high voltage capacitor is suspended on an overhead line at 110kV in parallel with the line insulator. Generally speaking, the highest Ac voltage of 110kV is 127kV; The 50% discharge voltage of the 110kV line insulator is 700kV. The lightning shock voltage is relatively high, at 800kV, and the dc shock voltage can be replaced by an equivalent lightning shock voltage.

This design uses cylindrical film capacitor to replace the the zinc oxide valve plate inside the zinc oxide arrester, and the overall size of the high voltage capacitor is determined by the size of the arrester. In this design, 10 thin film capacitors with a length of 100mm, a diameter of 50mm and a dc withstand voltage of 80kV are finally selected to be connected in series and molded by silicon rubber.
3.1.2 Confirmation of capacity
Cylindrical thin film capacitors can be equivalent to plate capacitors, and a formula can be used to estimate the capacity of a capacitor, in which $A$ is the material coefficient, and $S$ is the area of the plate ($m^2$), and $d$ is the spacing of the plate (m). The series of $N$ identical capacitors is equal to $d$ plus $N$.

$$C_{\text{tandem}} = \frac{C}{N} = A \frac{S}{N d} \quad (1)$$

In formula (1), multiply $Nd$ $(D = Nd)$ in both numerator and denominator, and apply $U_{50\%} = kD$ into the formula to obtain.

$$C = A \frac{S N d}{(Nd)^2} = A \frac{V}{k} \left( \frac{U_{50\%}}{U_{50\%}} \right)^2 = B \frac{V}{(U_{50\%})^2} \quad (2)$$

In formula (2), $U_{50\%}$ and $V$ are the 50% discharge voltage and volume of the capacitor respectively. It can be seen that the capacity of the capacitor has nothing to do with the number of series, and is proportional to the volume, and is inversely proportional to the square of 50% discharge voltage. Finally, each parameter is introduced into formula (2) to solve the capacity of the high voltage capacitor $C = 600 \mu F$.

3.2 Design of voltage regulator module and voltage control comparator

3.2.1 Voltage Regulator Module
The specific structure is shown in figure 2:

**Fig.2 Rectifier filter regulator circuit**

As shown in the above, CON2 terminal voltage is AC220V, after Pre-capacitor and inductance primary filtering, then AC/DC conversion is performed on the D3 bridge rectifier, and the transformed dc voltage is divided through three series resistors. Take the voltage between R1 and R30 as the forward input voltage of the voltage comparator LM358, and at the other end, the input voltage at the NULL end is 5.1v. Through the operation of the comparator, the output end is the signal of positive and negative polarity transformation, which then enters the subsequent voltage follower that acts as isolation. As the voltage follower plays the role of transmitting variable voltage, terminal 7 outputs the signal of the same polarity as terminal 1. The output voltage of terminal 7 is the driving voltage of the subsequent MOSFET tube.

Principle analysis: the voltage of the CON2 terminal after a bridge rectifier $V_{TC}$=311V, the voltage between R1 and R30 $V_{1}=5.1V, V_{null}$ input voltage as the ends of the voltage comparator. The voltage amplitude has a small deviation of volatility of about 5.1V. As the voltage of $V_{null}$ is fixed at 5.1 V, the voltage signal outputted from the voltage comparator is also unstable. Two situations will appear: (1) if $V_{1}$ voltage is higher than 5.1V due to the voltage increase of the front-end circuit, the outputted positive polarity voltage breakover the MOS tube, then $I_{D}$ will rise and $V_{D}$ will fall at the same time, thus lowering the raised voltage of the front-end; (2) if the voltage of the front-end circuit is less than 5.1v due to the increase of the voltage of the front-end circuit, the outputted negative polarity voltage can also breakover the MOS tube, but $I_{D}$ will decline and $V_{D}$ will rise at the same time, thus raising the voltage of the front-end.

3.2.2 Voltage control comparator design
The specific structure is shown in figure 3
Fig.3 Amplifier circuit

As shown in the figure above, the 1P and 2P terminals are connected to the switching power supply, which is equivalent to the TG terminal. The series segment is the switching power supply and small resistance, and finally the voltage at both ends of R8 is obtained and used. In the design, the output power is required to be 100W. If the highest output power is assumed, at this time the current $I = 0.32A$, $U = IR = 105.6$, and the voltage divided by R8 is amplified by 100 times through two-stage operational amplifier, and the maximum output voltage is 11V.

Fig.4 Voltage comparison circuit

As shown in Fig. 4, VG terminal is the output terminal in Fig. 3, and the maximum voltage is 11V, and the Vcc is 12V. The voltage of the following nodes is 8V, 6V, 4V, 2V, and LM339 are four voltage comparators. The VG terminal voltage is compared with the voltage of 4, 6, 8 and 10 terminals. According to the comparison results, the voltage comparator sends out positive and negative signals.

As shown in figure 5, the G1, G2, and G3,G4,meet the output in figure 3 respectively, relay drive ULN2003A can be seen as an inverter which reverses the polarity of the voltage at terminals 1, 2, 3 and 4 to control the closure of the relay, thus controlling the on and off of R14, R15, R16 and R17 (initial status is full closure, the LED lights are on), to meet the use of power of on-line monitoring equipment.

4. Comprehensive Test

4.1 Voltage stabilization when Ac voltage changes

In order to verify the effect of voltage regulation module and the effect of limiting PT primary side voltage, this test recorded the changes of PT primary side and secondary side voltage with the increase of Ac voltage. Since the stable working phase voltage of 110kV line is 63.5kV and the highest over voltage is 127kV, the first terminal voltage is raised to 127kV to observe the operation of the whole set of devices under this condition. The experimental results are shown in table 1. In table 1: U1 is the Ac applied voltage, U2 is the primary side voltage of PT, and U3 is the secondary side voltage of PT.

| U1/kV | U2/kV | U3/V | U1/kV | U2/kV | U3/V |
|-------|-------|------|-------|-------|------|
| 4.9   | 1.54  | 33.25| 55.2  | 8.45  | 182.7|
| 14.8  | 2.78  | 59.9 | 63.5  | 9.89  | 216.3|
As can be seen from the table 1, with the increase of AC voltage, PT primary side voltage is also increasing linearly. When the AC voltage rises to around 63.5 kV, PT primary side voltage basically reach rated voltage 10 kV, after which AC voltage is raised to 127 kV, and voltage has remained a very small range of fluctuation at around 10 kV, almost close to a straight line. This indicates that (1) the power taking device can run well in a short time under over voltage; (2) the voltage stabilizing effect of the voltage stabilizing module is good, and the primary side voltage of PT is controlled at about 10kV.

4.2 situations when power changes

In order to verify the effect of the output power control relay of the subsequent circuit, this paper tests the power variation of the power taking device. The output voltage of the power supply is 24V, and the switching conditions of the four LED lights connected with the resistance are recorded under the condition of different output power (by adjusting the switching power supply), as shown in table 2.

| the power (W) | the situation of LED lights |
|--------------|-----------------------------|
| 0W           | Total extinction            |
| 30W          | 1 on, 3 off                 |
| 50W          | 2 on, 2 off                 |
| 70W          | 3 on, 1 off                 |
| 100W         | All on                      |

It can be seen from the data in table 2 that the power change control relay of the power taking device has a good effect. After calculation and analysis, the power consumed by each resistor is almost the same as that of the MOS tube, which is about 24W and will allocate the power consumed to meet the power consumed by the online monitoring device.

5. Conclusion

This paper presents a power supply device based on the principle of high voltage capacitor step-down. Through the comprehensive test of the power supply device, the test result is good and the performance is stable, which can provide stable and effective low-voltage power supply for the on-line detection device of 110kV high-voltage multiple circuit.

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