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A De-icing Method of Electric Transmission Line by Adjusting Load Based on Controllable Inductor and Capacitor Compensation

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***Abstract*--The transmission line de-icing method based on adjusting electric load is studied by using controllable inductor and capacitor compensation, in order to reduce and avoid the impact of the freezing rain and ice disaster. The technical and economic feasibilities of various ice-melting methods are briefly compared and analyzed between inductor-adjusting-load, short-circuit and over-current. The theoretical models and calculations of inductor-adjusting-load are proposed. The implementing method of inductor-adjusting-load for connecting transmission lines is given based on 220kV Xinghua Primary Substation 66kV System in Jixi Electric Power Bureau. The calculation of de-icing current and volume of controllable inductor are also given. The key equipment and the necessity of applying inductor-adjusting-load technique are described and discussed. In conclusion, the inductor-adjusting-load method is practical in technology and feasible in economy.**

***Index Terms*--Capacitor compensated transmission lines, De-icing method, Electric breakdown, Electric heating, Freezing rain, Ice disaster, Inductor adjusting load, Power system restoration, Power transmission faults, Temperature.**

I. Introduction

In the early of 2008, there is a long term and large range freezing rain and ice disaster in the Southern China, which causes many accidents and disasters on power transmission network system, such as tower failure, disconnection, galloping, ice flashover, sleet jump, and etc[1]-[4]. This freezing rain and ice disaster makes an ever seen damage on power distribution network in Hunan Province, Jiangxi Province, Anhui Province, Hubei Province, Guizhou Province, Guangxi Autonomous Region and etc. in China.

Under the joint efforts from all aspects in China, the damaged power distribution networks are rebuilt and recovered. However, the level of resisting disaster does not improve and rise significantly. It needs long time to raise and ensure the ability of network on resisting a fifty year frequency disaster. Therefore, it is emergent to do researches on transmission line ice-melting methods and techniques. During the period of disaster, the Power Grid Company and other relatives organizations adopt some methods of ice-melting[2][4], which are limited by meteorological conditions, operation conditions, network structure and technologies[3]-[6], the implementation of methods are difficult and results of application are not acceptable.

Currently, there are more than 30 methods have been proposed around world, which mainly divided to thermal ice-melting methods, mechanical de-icing, and spontaneous de-icing[8][14]-[17]. In recent years, the researches focus on electric pulse de-icing and thermal de-icing. The thermal de-icing methods including:

Short circuit ice-melting[11], which is theoretically feasible, however, the de-icing loop is limited by network structure and the operations are complicated and need to cut power. Short circuit current, which is limited by voltage and transmission line condition, is difficult to adjust and control.

Adjusting electric load ice-melting methods[12][13], can not practice at radiation structured network, due to the maximum load is constant and the ice-melting loop has no connection to other substations, which causes the load can not be adjusted. This method can be implemented in ring structured network by de-connecting the loop. By adapting the adjusting electric load ice-melting methods, the load is hard to adjust and control, power supply can be interrupt sometimes, and the workload of scheduling and operating is massive.

DC current ice-melting method[1], needs DC power sources or power electronics devices, which cost are relative expensive. Thermal de-icing combined with static var compensation (SVC) still need to be improved.

This paper is based on thermal ice-melting method, proposed a method of ice-melting based on adjusting electric load by using controllable inductor and capacitor compensation, in order to de-ice the power transmission lines.

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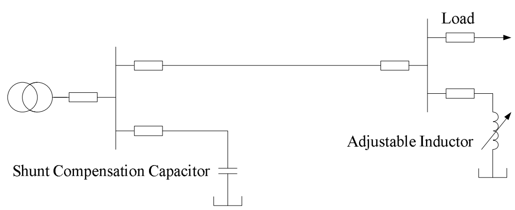
This method can solve some problem which other methods can not overcome and it practices in the working field conveniently.

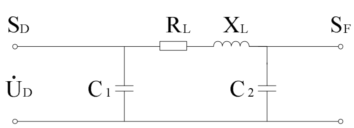
II. The Basic Theory of Inductor-Adjusting-Load Method

The theory and method of inductor-adjusting-load and capacitor compensation is implemented by installing the shunt capacitor at the power supply side and installing the adjustable reactor at load side. Through adjusting the reactive value of inductor to modify the current in the de-icing loop, the transmission line is overloaded and the temperature is rising in order to melt ice. To prevent voltage drop, the shunt capacitor is connecting to the source, providing reactive power supply and reactive current. During the de-icing period, the transmission line can provide normal power supply. The theoretical circuit for adjusting electric load based on controllable inductor and capacitor compensation method is shown in Fig. 1.

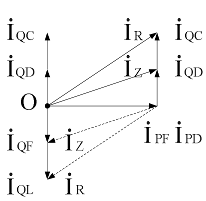
In Fig. 1. (a), the neutral points of the shunt compensation capacitor and the adjustable inductor are not connected to earth, therefore, they can not structure parallel or series loop. Concurrently, the adjustable inductor and capacitance to ground can not be structured parallel or series loop as well. Under the condition of normal system operation, there is no condition of resonance.



(a) Theoretical Diagram.



(b) Theoretical Diagram of Equivalent Circuit.



(c) Current Vector Diagram of Equivalent Circuit.

Fig. 1. The Theoretical Circuit for Adjusting Electric Load Based on Controllable Inductor and Capacitor Compensation.

When transmission line has single-phase disconnection, shunt compensation capacitor and capacitance to ground structure series loop with the parallel adjustable inductor. There will be resonance if the parameters are matched. Therefore, the method of inductor-adjusting-load and capacitor compensation can not be adopted when the transmission line is broken. The breaking protection should be installation in the loop in order to prevent the resonance in case of line disconnection to prevent resonance.

In Fig. 1. (a), the shunt compensation capacitor is used to de-icing by transporting the var current to the load through the de-icing transmission line, which is installed at the power supply side. The total current is modified by changing the reactive value through adjustable inductor, which make the temperature of transmission line rise and gain the aim of ice-melting.

The theoretical diagram of equivalent circuit can be seen in Fig. 1. (b). The shunt compensation capacitor is equivalent to reactive power supply $\dot{U}_D$, the adjustable inductor is equivalent to reactive load.

The definition of parameters is shown below:

S_D is apparent power, P_D is active power, jQ_D and jQ_C are reactive power of power supply and reactive power of compensation capacitor on power supply side, S_F is apparent power, P_F is active power, jQ_F and jQ_L reactive power of load and reactive power of adjustable inductor on load side, R_L and X_L is resistance and reactance, C_1 and C_2 are capacitances to earth of de-icing loop, respectively, where $S_D = P_D + (jQ_D + jQ_C)$ and $S_F = P_F + (jQ_F + jQ_L)$.

The relationship between each current vector showed in Fig. 1. (c), where $\dot{I}_R$ is total current of de-icing, $\dot{I}_Z$ is total current of load, $\dot{I}_{PD}$ and $\dot{I}_{QD}$ are output active current and reactive current of power supply, $\dot{I}_{PF}$ and $\dot{I}_{QF}$ are input active current and reactive current of load, $\dot{I}_{QC}$ and $\dot{I}_{QL}$ are output reactive current of shunt compensation capacitor and input reactive current of adjustable inductor, respectively.

The ice-melting current can be calculated by using the equation shown as below:

$$\dot{I}_R = \sqrt{\dot{I}_{PF} + (\dot{I}_{QF} + \dot{I}_{QL})}$$

From current vector diagram of equivalent circuit which is shown as Fig. 1. (c), it can be seen that the reactive current $\dot{I}_{QL}$, which inputs the adjustable inductor, is superposition with the reactive current of load, provided by power supply side. Due to input reactive current of the adjustable inductor $\dot{I}_{QL}$ increase, the total de-icing current of loop $\dot{I}_R$ is increased. This is characteristic of the remote places reactive compensation. It is different from on site reactive compensation, which does not require transport reactive current from power supply and the total current is decreased.

III. The Researches of Applications and Practices on Inductor-Adjusting-Load Ice-melting Method

In China, the structure of electric grid below 220kV is radiation type. Most of important networks are double loop power supply modes. Therefore, it is an ideal platform for applying inductor-adjusting-load ice-melting method. Now, we consider 220kV Xinghua primary substation 66kV system of Jixi Electric Bureau as the typical research object, discuss the applications and practices on inductor-adjusting-load ice-melting method.

A. Volume of the Parallel Adjustable Inductor

Specification of 66kV transmission line in Xinghua primary substation is LGJ70～LGJ185. Therefore, the ice-melting condition which is satisfied with type LGJ185, is satisfied with the condition of other type transmission line as well. The calculation on the volume of parallel adjustable inductor needs to be derived. Under the environment temperature 25 ℃, the allowable current of LGJ185 transmission line at the line temperature 70℃ is 368A. Under the environment temperature -16℃, the minimum ice-melting current of LGJ300 transmission line is 700A[1]. Under the same condition, the ice-melting current of LGJ185 is derived as $I_R = 700/300 \times 185 = 440\text{A}$ in proportion. The load current of ice-melting I_Z, which is calculated as 60% of allowable current, is 368×60%≈220A. If the load power factor is considered as 0.85, the load active current $\dot{I}_{PF}$ is derived as

$$I_{PF} = I_Z \times 0.85 = 220 \times 0.85 = 187\text{A}$$

The load reactive current $\dot{I}_{QF}$ is derived as

$$I_{QF} = \sqrt{I_Z^2 - I_{PF}^2} = \sqrt{220^2 - 187^2} = 116\text{A}$$

The input reactive current of the parallel adjustable inductor $\dot{I}_{QL}$ is derived as

$$I_{QL} = \sqrt{I_R^2 - I_{PF}^2} - I_{QF} = \sqrt{440^2 - 187^2} - 116 = 282\text{A}$$

Taking the approximate of I_{QL} equal to 300A, the volume of parallel adjustable inductor is derived as

$$\begin{aligned} jQ_L &= \sqrt{3} \cdot U \cdot I_{QL} \\ &= \sqrt{3} \times 66\text{kV} \times 300\text{A} \\ &= 34294\text{kvar} \end{aligned}$$

Therefore, the volume of parallel adjustable inductor is equal to 40Mvar approximately.

B. Volume of the Shunt Compensation Capacitor

The volume of the shunt compensation capacitor should bigger than the volume of parallel adjustable inductor to avoid resonance, which is caused by the parameter match, when transmission line is disconnected accidently. The inductive reactance and capacitive reactance are derived as $jX_L = j\omega L = \dot{U}_m / \dot{I}_m$ and $-jX_C = -j(1/\omega C) = \dot{U}_m / \dot{I}_m$, respectively. The condition of series resonance is $X(\omega_0) = \omega_0 L - 1/(\omega_0 C) = 0$. The volume of the shunt compensation capacitor is chosen as 50Mvar, bigger than the volume of parallel adjustable inductor 40Mvar.

The transmission line gains the ability of ice-melting when the determined shunt compensation capacitor and parallel adjustable inductor are installed.

C. The Application of Inductor-Adjusting-Load Ice-melting Method in 220kV Xinghua Primary Substation 66kV System

The connection of 220kV Xinghua primary substation 66kV system is shown in Fig. 2. Consider the double loop of Beigang substation as an example, when implementing ice-melting operation on Xianggangjia line and Xinggangyi line, using Xinggangjia line as the power supply to the 66kV bus of Beigang substation, then using Xinggangyi line back to 66kV bypass bus (C) of Xinghua primary substation. The adjustable inductor is installed on bypass bus and shunt compensation capacitor is installed on 66kV bus A or B. Thus, a complete ice-melting loop is set up.

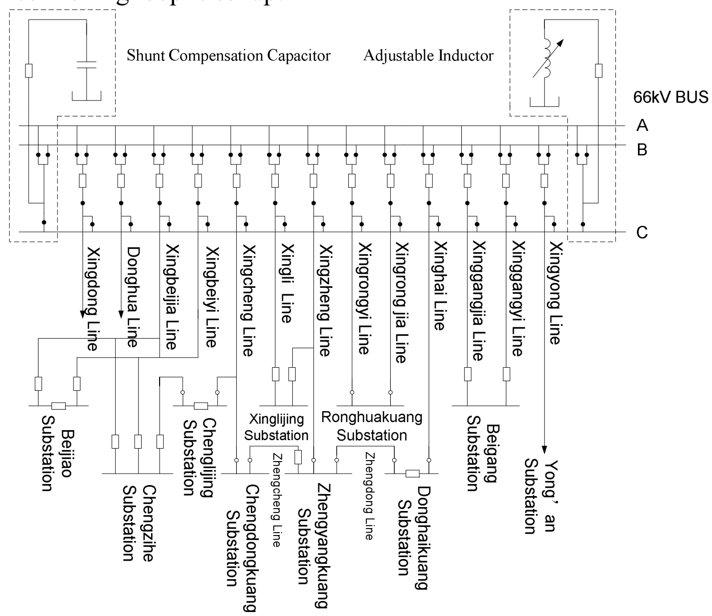


Fig. 2. Diagram of 220kV Xinghua Primary Substation 66kV System

The specification of Xinggangjia line and Xinggangyi line is LGJ185. The ice-melting current is 440A. The ice-melting current can be raised to 440A by adjusting the inductor. Using infrared thermometric instrument to monitor the line temperature and observe the ice-melting at the output gate of the line, when implementing the de-icing operation. Adjust the inductor to reduce the current to minimum value on the line when the de-icing mission is completed. Then shut down the switches of the adjustable inductor and shunt compensation capacitor. The Xinggangjia line and Xinggangyi line is back to normal power supply mode after de-icing. The similar operations of de-icing can be implemented on other transmission line in 220kV Xinghua primary substation 66kV System.

In Fig. 2, Chenglijing substation, Xinglijing substation, Chengdongkuang substation, Zhengyangkuang Substation, and Donghaikuang substation are mutual backup connection mode based on single substation and single line. Two or more substations can be combined for de-icing operation, such as Zhengyangkuang substation can combined with Donghaikuang substation through Xingzheng line to supply (shut down the switch to Xinglijing substation) to the bus of Zhengyangkuang substation (shut down the switch to Zhengcheng line), then through Zhengdong line to the bus of Donghaikuang substation, and by Xinghai line back to 66kV bypass bus of Xinghua primary substation, to construct a de-icing loop. The similar operations of constructing de-icing loop can be implemented on other transmission line as well.

D. The Application of Inductor-Adjusting-Load Ice-melting Method in Different Electric Grid Architecture

The inductor-adjusting-load ice-melting method is suitable for most of electric grid architecture in China. It can be implemented conveniently in radiation type of electric grid and does not affect power supply when de-icing. It is relatively easy to build the de-icing loop with less amount operation. It is also highly controllable and reliable. Installing a set of de-icing equipment in 220kV substation can adjust many transmission lines and the utilization efficiency is high.

When applying inductor-adjusting-load ice-melting method in ring structured network, the transmission line need to de-connect from network. 220kV line can be de-iced by using 66kV reactor through 220kV primary substation. Due to the volume of adjusting inductor, it needs several substations to join together in order to satisfy the condition of ice-melting.

Comparing with the method on 66kV radiation type of network, 220kV radiation type of network can also implement the inductor-adjusting-load ice-melting method. It needs other substation to provide reactive power supply when de-icing a single line in one substation.

The inductor-adjusting-load ice-melting method is not only suitable for 66kV and 110kV networks, but also suitable for 220kV and 10kV networks. The de-icing condition in 10kV networks is also allowable and many substations have installed 10kV capacitors. To implement the de-icing operation, it is only need to install an adjustable conductor.

IV. The Key Equipment of Inductor-Adjusting-Load Ice-melting Method

The inductor-adjusting-load ice-melting method is conveniently implemented and feasible. The key of application is the adjustable reactor. The technology condition is mature in manufacturing. The adjustable reactor with giant volume has huge market, while the whole society and market focuses on safety production and disaster reduction. The world largest fixed type 320Mvar/1000kV giant volume reactor is successfully developed at Xi’an, China at present. The 10Mvar adjustable reactor is widely used in electric network. There is no technical obstacle in developing 66kV and 220kV high volume adjustable reactor. However it needs financial supports from government and relevant organizations.

V. The Necessities of Applying the Inductor-Adjusting-Load Ice-melting Method

The reconstruction of transmission line after freezing rain and ice disaster is under the previous standard. The abilities of disaster resistance are not improved. It is necessary to investigate the methods and applications on emergent de-icing.

The Consideration and Response Seminar on Disaster Preventing in Electric Power Industry was hold in Beijing, China on Match 11th. During the seminar, the Professor Cui from Electric Power University of Northern China has pointed that the consumption of material is 2.2～3.4 times and cost is 1.8～2.6 times if the ability of resisting ice coating is increased from 10mm to 20～30mm under the calculation on 500kV transmission line.

Highly cost of construction and economy feasibility are the key issues need to be considered. It is equivalent to rebuild a newly nation wide network if the whole network is raised to the higher standard of disaster resistance. It is nearly infeasible and it takes long time. The new modified construction standard of power network is under discussed. The newly built network has a high level of disaster resistance, however, the old network need to update. Under syntheses and analyses, the inductor-adjusting-load method is practical in technology and feasible in economy.

VI. Conclusions

1) By analyzing the inductor-adjusting-load ice-melting method, the theoretical feasibility has been proved. The shunt compensation capacitor, which is installed in substation, can be used as reactive compensative device during the normal power supply mode.

2) The application and practice of inductor-adjusting-load ice-melting method has been investigated through network of 220kV Xinghua primary substation 66kV system. It is convenient to construct the de-icing loop with relative less operation and effect of power supply. It also has high controllability and reliability. The application of this method is feasible.

3) The volume of shunt compensation capacitor is approximate at 50Mvar～60Mvar can satisfy with the de-icing condition under the derivation and calculation. The technology in this field is matured at present and it is feasible to manufacture.

4) The application of the inductor-adjusting-load ice-melting method will save massive cost of reconstruction. The installation of shunt compensation capacitor and parallel adjustable inductor is convenient with less amount workload. The inductor-adjusting-load method is practical in technology and feasible in economy.

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