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MODELING AND ON-SITE EXPERIMENTS OF SHUNT CAPACITOR COMPENSATION METHOD FOR DEICING OF 66KV POWER LINE

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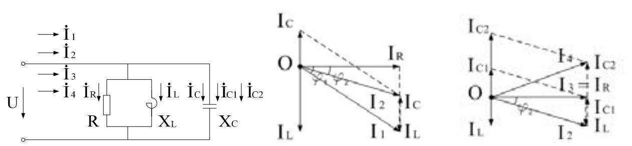
Abstract: An EMTP-ATP model and a MATLAB model of 66kV double line network are built and simulated. By applying shunt capacitor compensation method for de-icing 66kV overhead transmission line within the models, the simulation results show an increase of the rms line current to 650A for the de-icing line which leads the cable temperature to increase. A COMSOL model for LGJ-120/20 cable is also built to simulate the temperature distribution of current-carrying ice covered cable. The simulation results show that the cable coated with 3cm thickness ice sleeve can be de-iced, which the surface temperature of the cable can be increased to above 310k after 40 minutes. Through the on-site experiment in Mishan primary substation 66kV transmission line, the real-time data were matched by both EMTP-ATP and MATLAB simulation results, which verified the effectivity and feasibility of the shunt capacitor compensation de-icing method.

1. INTRODUCTION

Utilize 10kV shunt capacitor installed in 220kV primary substation to implement the temperature-rising operation. By connecting shunt capacitor to the de-icing transmission line, the total current in the conductor can be controlled. This method can increase total current and de-ice the power line.



(a) Theoretical Circuit (b) Compensation (c) Over-compensation

X_C —Capacitive Reactance; R、X_L —System Load

Figure 1: Theoretical Circuit of Shunt Capacitor Compensation

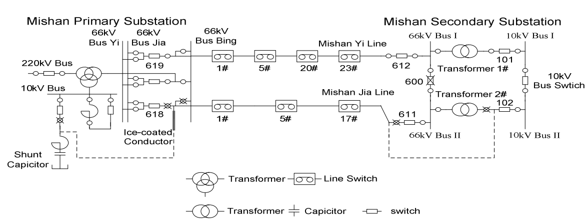
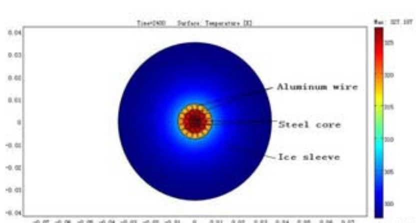


Figure 2: De-icing Experiment Wiring Diagram of 66 kV Double Line Network

2. RESULTS AND DISCUSSIONS



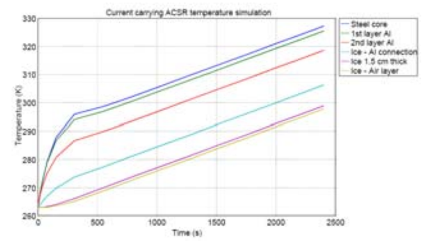


Figure 2: Temperature Distribution and Simulation Results of Ice Covered LGJ-120/20 Cable after 40 Minutes

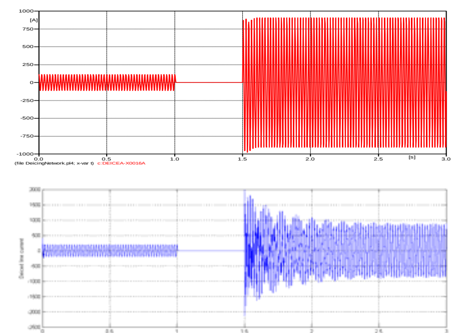


Figure 3: EMTP-ATP and MATLAB Simulation Results of Deicing Line

Figure 4: On-site De-icing Processes of Experimental Conductor

3. CONCLUSION

A 3.5km long LGJ-120/20 cable with 3cm thickness ice sleeve can be de-iced within 40 minutes by using shunt capacitor compensation de-icing method.

4. REFERENCES

[1] Masoud Farzaneh. Atmospheric Icing of Power Networks[M]. Springer, 2008.

[2] WEN Kai-Cheng. Study on Feasibility of Ice-Melting for Long HV Transmission Lines by Short-Circuit Method [J]. Power System Technology, 2009, 33(2):46-50.

[3] Gang Liu, Hui Peng, M Lehtonen, et al. De-icing Schemes and Operations for Overhead Power Line Based on Shunt Capacitor Over-compensation Method [C]. 2010 International Conference on Electrical and Control Engineering.(2010 iCECE), Wuhan, China.

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***Abstract*—An EMTP-ATP model and a MATLAB model of 66kV double line network are built and simulated in this paper. By applying shunt capacitor compensation method for deicing 66kV overhead transmission line within the model, the simulation results show an increase of the rms line current to 650A for the deicing line which leads the cable temperature to increase. A COMSOL model for LGJ-120/20 cable is also built to simulate the temperature distribution of current-carrying ice covered cable. The simulation results of the Multiphysics model show that the cable coated with 3cm thickness ice sleeve can be deiced, which the surface temperature of the cable can be increased to above 310k after 40 minutes. Through the on-site experiment in Mishan primary substation 66kV transmission line, the real-time data were matched by both EMTP-ATP and MATLAB simulation results, which verified the effectivity and feasibility of the shunt capacitor compensation deicing method.**

Keywords-deicing; shunt capacitor; compensation; thermal deicing; overhead power line; 66kv; modeling; simulation

I. INTRODUCTION

Atmospheric icing cause serious damages on overhead transmission lines due to ice accumulation on conductors. Excessive ice on conductor is responsible for partial discharge, galloping or even tower collapse [1,2]. Considerable literatures classify various de-icing techniques into four main categories [3]: (1) Thermal methods based on the melting of the ice [4-10]; (2) Mechanical methods based on the breaking down of the ice [3, 11]; (3) Passive methods based on natural forces [12-15], and (4) Diverse methods based on fundamentals different from the three preceding classes [16].

Thermal methods are currently recommended and in use by several electric utilities. The majority of thermal methods use melting of ice accumulated on the conductor by means of joule effect, while having a higher current from the nominal current which circulates inside the conductor. Also conductor heating or mechanical de-icing using roller is possible for over head lines ranging from 25V to 245 kV. Although thermal methods require around 100 times more energy than mechanical methods, there are many vantages, particularly Joule-effect methods, permit the de-icing of longer line section and require less manpower. Now developing an efficient and economical technique of joule effect heating is an issue. Generally, using AC de-icing method does not involve adding high-cost equipment, since the required current is supplied directly to the line. Quite often the melting current must be very high for long transmission lines. With this respect we studied and evaluated the shunt capacitor compensation method [8-10] for deicing of 66kV transmission line, which uses the already installed facilities by an appropriate re-closing sequence with minor wire connections.

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II. THE PRINCIPLE OF SHUNT CAPACITOR COMPENSATION METHOD

Shunt capacitors for supplementing the reactive power source are installed within the grid in order to increase the transmitting capacity of power grid and decrease wire losses. The theoretical circuit is as in Fig.1. By installing the shunt capacitors, power factor angle is decreased from φ_1 to φ_2 and total current decrease from I_1 to I_2, respectively. By improving the power factor, wire losses are decreased. When reactive compensating current I_{C1} is equal to reactive load current I_L, the power factor $\cos\varphi$ is equal to 1. The total load current I_3 is minimum and equal to active load current I_R, which is shown in Fig.1(c). When reactive compensating current I_{C2} is larger than reactive load current I_L, the total load current is increased to I_4, where $I_4 = \sqrt{I_R^2 + I_C^2}$, it is called over-compensation. The excessive reactive power current I_{C2} is transmitted to grid by conductor.

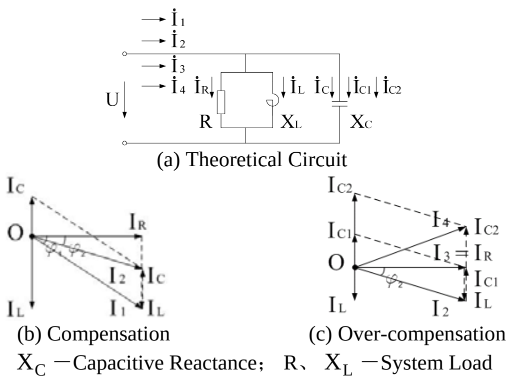


Figure 1. Theoretical Circuit of Shunt Capacitor Compensation

By connecting shunt capacitor banks to the de-icing transmission line, the total current in the conductor can be controlled. This method can increase total current and rise temperature of conductor, furthermore to de-ice the ice-coating of power line. The experimental scheme of shunt capacitor compensation method for de-icing 66kV power line is shown as Fig.2.

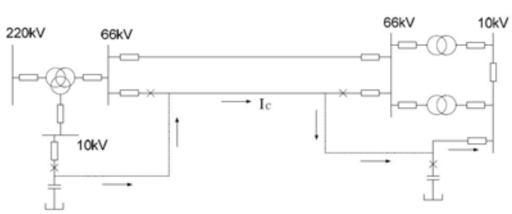


Figure 2. Experimental Scheme of Shunt Capacitor Compensation Method for De-icing 66kV Power Line

Utilize 10kV capacitor installed in 220kV primary substation in order to implement the temperature-rising operation. The operation procedures of de-icing 66kV transmission line are shown as below:

(1) Power cut one 66kV transmission line which is ready to be de-iced, power cut 10kV capacitor in 220kV primary substation and 10kV capacitor in 66kV secondary substation. At present, 66kV secondary substation is power supplied by another 66kV transmission line.

(2) 220kV primary substation: disconnect the 10kV shunt capacitor and remove it from capacitor switch, connect this 10kV capacitor to the 66kV transmission line which is ready to be deiced.

(3) 66kV secondary substation: disconnect the 10kV shunt capacitor and remove it from capacitor switch; connect the 66kV de-icing transmission line to 10kV capacitor switch, which is connected to 10kV bus. Therefore, the loop for de-icing is constructed.

(4) Close 10kV capacitor switch of 66kV substation. The reactive current I_C is transmitted to 66kV secondary substation 10kV bus through 66kV power line and power line temperature will be increased. At present, the voltage level of the de-icing line is 10kV.

III. COMSOL Model and Simulation of Ice-Coated LGJ-120/20 Cable

Reference [4] gives calculations of conductor temperature rising with ice-coating. For de-icing LGJ-150 type of transmission line with 2cm thickness ice, the current density is $4.2A/mm^2$. In our case, the cable used for the network is ACSR type where its model name is LGJ-120/20 and ice thickness is 3cm. Considering the environment factors, we calculated and modified the deicing current as 650A to ensure the de-icing current is sufficient. Table I. and Fig.2 show the parameters and specifications of LGJ120/20 cable. In the COMSOL simulation, an initial temperature of 263 K (-10 ^{o}C) was considered.

TABLE I. Parameters of LGJ120/20 Cable

Aluminum wire	***Number***	26
	Diameter	2.38 mm
Steel core	***Number***	7
	Diameter	1.85 mm
Nominal cross section		120 mm2

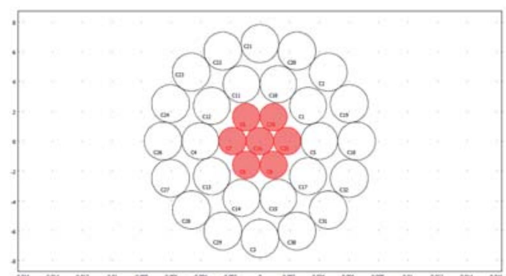


Figure 3. Specifications of LGJ120/20 Cable

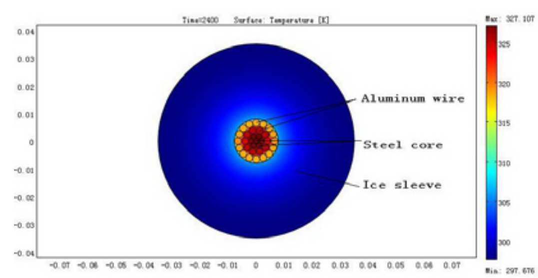


Figure 4. Temperature Distribution of Current Carrying Ice Covered LGJ-120/20 Cable after 40 Minutes

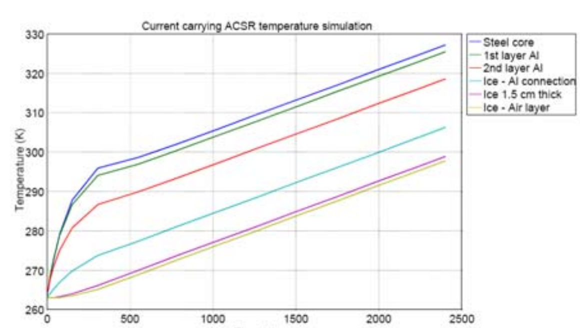


Figure 5. Temperature Simulation Results of Current Carrying Ice Covered LGJ-120/20 Cable

Fig.4 shows temperature distribution of current carrying ice covered LGJ-120/20 cable after 40 minutes. From Fig.5, it can be seen that the COMSOL simulation results show significant and safe temperature increment in the inner conductor which later radiated outward to the 3 cm thickness ice and increasing its temperature by 34 degree from its initial temperature of 263 K. The COMSOL model verifies that 650A (rms line current) is effective and sufficient for de-icing LGJ-120/20 cable.

IV. EMTP-ATP MODEL AND SIMULATION OF 66KV DOUBLE LINE NETWORK

The idea behind this method is deploying the shunt compensating capacitor in the primary substation to de-ice the lines one after another using proper re-closing order of circuit breakers. Assuming primarily the double line network is supplying the load and the line distance is 3.5km with the cable type is LGJ-120/20. The EMTP-ATP model and operating procedure of de-icing are shown below:

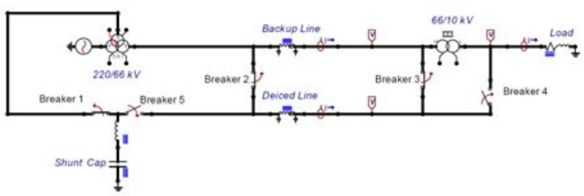
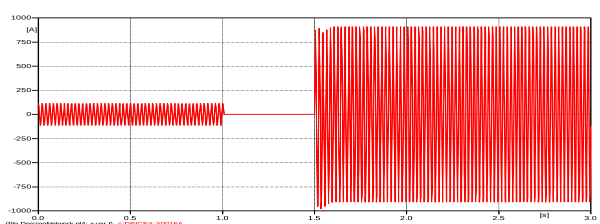


Figure 6. EMTP-ATP Model of 66 kV Double Line Network

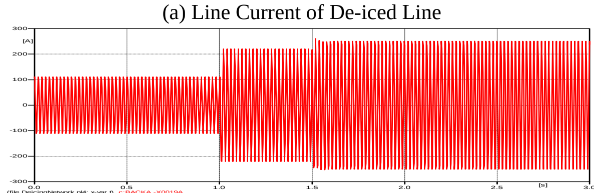
Step#1: Initially circuit breakers 1, 2 and 3 are closed and supplying the load while circuit breakers 4 and 5 being open. The 66kV secondary substation is supplied by both de-icing line and backup line. The voltage level of both de-icing line and backup line is 66kV.

Step#2: Open breakers 1, 2 and 3, after which the 66kV secondary substation is supplied solely by the backup line. Following zero crossing time of voltage, close circuit breakers 4 and 5 undermining transient voltage.

Step#3: After waiting the appropriate time for deicing, return to the double network system by reversing the above orders. Also follow the same procedure for deicing the other line.



(a) Line Current of De-iced Line



(b) Line Current of Backup Line

Figure 7. Current from EMTP-ATP De-icing Simulation Resutlts

Note that the capacitor bank in this network stayed on 10kV level throughout the whole process. From Fig.7, it can be concluded that the line current of the de-icing line is 900A, which I_p =900A , and therefore rms line current I_e is approximate 640A.

V. MATLAB MODEL AND SIMULATION OF 66KV DOUBLE LINE NETWORK

In order to double check the shunt capacitor compensation method for de-icing of 66kV power line, a MATLAB model and simulation are done, which is shown as Fig.8 and Fig.9.

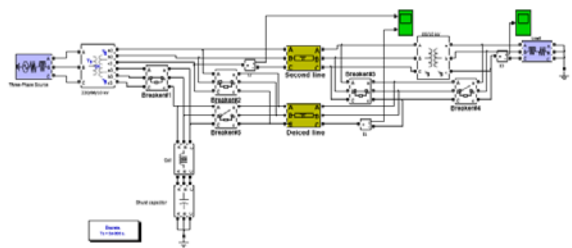
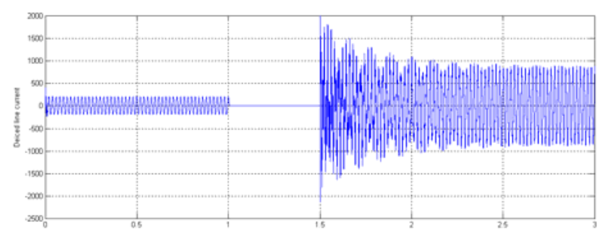
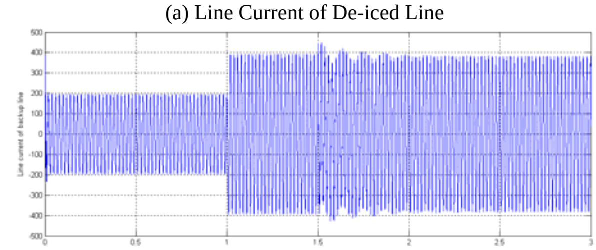


Figure 8. MATLAB Model of 66 kV Double Line Network



(a) Line Current of De-iced Line



(b) Line Current of Backup Line

Figure 9. Current from MATLAB De-icing Simulation Resutlts

Compare with MATLAB model and EMTP-ATP model, it can be concluded that the shunt capacitor can provide about 650A rms line current, which is sufficient for de-icing 3.5km long LGJ-120/20 cable with 3cm ice sleeve. It establishes a foundation of on-site experiment of shunt capacitor compensation method for de-icing 66kV double line network.

VI. ON-SITE EXPERIMENT OF 66KV DOUBLE LINE NETWORK

The on-site experiment was conducted on December 11th, 2009 in Jixi electric power bureau, Northeast of China [17]. The 66kV double line connects to Mishan primary substation and Mishan secondary substation located 3.5 km apart. The experimental measurements of the shunt capacitor deicing are provided in the following figures.

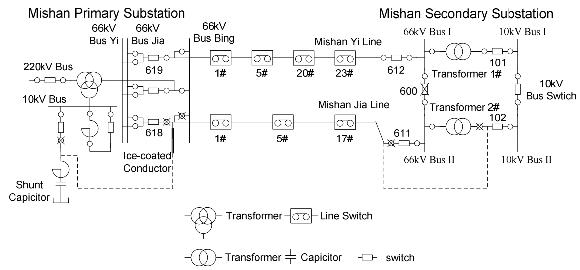
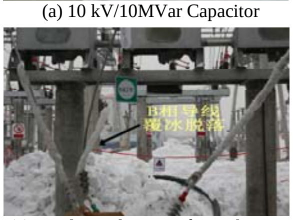


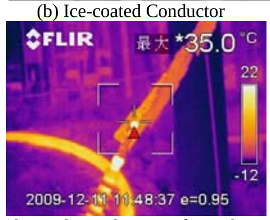
Figure 10. De-icing Experiment Wiring Diagram of 66 kV Double Line Network

(a) 10 kV/10MVar Capacitor

(b) Ice-coated Conductor



(c) Ice sleeve dropping from phase B



(d) Ice sleeve dropping from phase C

Figure 11. On-site De-icing Experiment

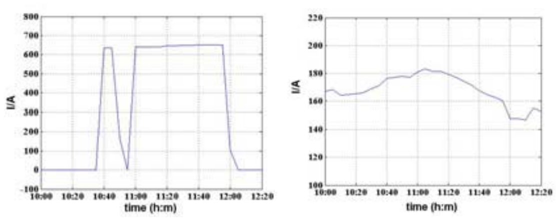


Figure 12. On-site Experimental Results of De-icing 66 kV Double Line Network

VII. CONCLUSIONS

The on-site experimental current of the de-iced conductor are matched by both EMTP-ATP and MATLAB simulation results. The on-site experiment and simulations show significant and safe temperature increment on the conductor with 3cm thickness ice. The temperature increases over 40 degree from its initial temperature of 263K. During the on-site experiment, it takes 37 minutes to melt the ice sleeve of phase B with an increment approximate temperature of 60 degree, which is matched by the COMSOL simulation as shown in Figure 5, an increase in conductor temperature of 57 degree was observed for the 40 minute simulation time.

The simulations and the on-site experiment verified the feasibility of shunt capacitor compensation method for de-icing 66kV double line network. By utilizing 10kV shunt capacitor to implement the de-icing operation, the 10kV bus of secondary substation can provide normal power supply to the load and does not necessary to cut off from the substation. The operating procedure is ease and does not require additional high-cost equipment. This gives a solid foundation to process other voltage ratings of transmission lines.

REFERENCES

[1] Huang Xinbo, Liu Jiabing, Cai Wei, et al. Present Research Situation of Iceing and Snowing of Overhead Transmission Lines in China and Foreign Countries [J]. Power System Technology, 2008, 32(4): 23-28.

[2] Yuan Jihe, Jiang Xingliang, Yi Hui, et al. The present study on conductor icing of transmission lines [J]. High Voltage Engineering, 2003,30 (1):6-10.

[3] Masoud Farzaneh. Atmospheric Icing of Power Networks[M]. Springer,2008.

[4] WEN Kai-Cheng. Study on Feasiblity of Ice-Melting for Long HV Transmission Lines by Short-Circuit Method [J]. Power System Technology, 2009, 33(2):46-50 .

[5] FU Chuang, RAO Hong, LI Xiaolin, et al. Development and Application of DC Deicer[J].Automation of Electric Power Systems,2009,33(11):53-56.

[6] Cloutier, R, Bergeron A, Brochu J. On-Load Network De-Icer Specification for a Large Transmission Network. IEEE Trans on Power Delivery, 2007,22(3): 1947–1955.

[7] Couture P. Switching Modules for the Extraction/Injection of Power (Without Ground or Phase Reference) From a Bundled HV Line. IEEE Trans. on Power Delivery, 2004, 19(3):1259–1266

[8] Gang Liu, Xuezeng Zhao, Yonghui Chen, et al. A De-icing Method of Electric Transmission Line by Adjusting Load Based on Controllable Inductor and Capacitor Compensation [C]. PowerTech 2009 IEEE Bucharest, June 28th-July 2nd, 2009.

[9] Gang Liu, Xuezeng Zhao, M Lehtonen, et al. An Overhead Transmission Line Temperature-rising Method and Experiment Based on Parallel Capacitor Compensating Reactive Power Source [C]. Asia-Pacific Power Energy Engineering Conference (APPEEC2010), Chengdu, China, March 28th -31st , 2010.

[10] Gang Liu, Hui Peng, M Lehtonen, et al. De-icing Schemes and Operations for Overhead Power Line Based on Shunt Capacitor Over-compensation Method [C]. 2010 International Conference on Electrical and Control Engineering.(2010 iCECE), Wuhan, China, June 26th - 28th , 2010.

[11] S. Montambault, J. Cote, M. St-Louis. Preliminary results on the development of a teleoperated compacttrolley for live-line working [C].2000 IEEE ESMO Conference:21-27, Montreal, Canada, Oct 8th -12th , 2000.

[12] Landry M, Beauchemin R, Venne A. De-icing EHV overhead transmission lines using electromanagnetic forces generated by moderate short-circuit currents[C]. Transmission and Distribution Construction, Operation and Live-Line Maintenance Proceedings of IEEE 9th international Conference, Montreal, Canada,2000:94-100

[13] Sullivan C R, Petrenko V F, Mccurdy J D, et al. Breaking the ice[J]. IEEE Industry Applications Magazine, 2003, 9(5):49-54.

[14] Ostendorp, M. Electromechanical fuse for storm damage mitigation and outage reduction on distribution line customer service drops[C]. IEEE 10th International Conference on Transmission and Distribution, Montreal, Canada, 2003:176-180.

[15] Petrenko VF, Whitworth RW, Physics of Ice. Oxford: Oxford University Press, 1999.

[16] Laforte C, Beisswenger A. Icephobic Material Centrifuge Adhesion Test. In: Proc 11th International Workshop on Atmospheric Icing of Structures, 2005, Montreal: 1–6.

[17] ZHAO Xue-zeng, LIU Gang, et al. De-icing Scheme and Experiment of 66kV Overhead Power Line Based on Shunt Capacitor Compensation Method[J], Automation of Electric Power Systems, in press.