Transient Analysis on Second Arc Current and Recovery Voltage of UHV Series Compensated Transmission Line

Zhang Yuanyuan, Ban Liangeng, Xiang Zutao, Han bin, Zheng bin, Ma wenyuan

***Abstract*-- State Grid Corporation of China plans to install series compensation on UHV transmission line in Changzhi-Nanyang-Jingmen UHV AC demonstration project of China in 2011. When series compensated line occurs single-phase ground fault, a low-frequency oscillation circuit is composed of series compensation, shunt reactor and arc resistor of short-circuit point. And at the circumstance, residual charge on series compensation discharges through the circuit, which increases low frequency component to second arc and recovery voltage, extends extinguishing time to second arc, and also has influences in single phase reclosing success rate. By using EMTP, this article researched the transient second arc current and recovery voltage of UHV series compensated line in Changzhi-Nanyang-Jingmen UHV AC demonstration project, calculated the impact of fault location and operation characteristics of UHV series compensation protection such as MOV, spark gap and by-pass switch. A linkage measure is also proposed in this article that by-pass switch of fault-phase series compensation is commanded to be closed while line protection monitors single-phase fault and commands line breaker to trip.. Under this measure, the fault-phase series compensation shall be bypassed during single phase reclosing, thus the low frequency components of second arc current and recovery voltage will quickly decay, and second arc extinguish faster.**

***Keywords*: UHV, series compensation, second arc current, recovery voltage, linkage measure.**

I. INTRODUCTION

UHV transmission technology is one of the cutting-edge technologies in world power science. The put into operation of Changzhi-Nanyang-Jingmen UHV AC demonstration project of China is a significant breakthrough for the country's UHV transmission development, brought the country to the forefront of the world power transmission technology. In order to develop transmission capacity of UHV AC line, State grid corporation of China plans to install series compensation on Changzhi-Nanyang-Jingmen UHV line, as the first case in the world.

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At present, EHV series compensation system in China usually use "MOV parallel gap combination" as overvoltage protection of series compensation as shown in Fig. 1. When the current or energy of MOV reaches the setting value, spark gap will be forced to trigger and by-pass switch to close. The fault-phase series compensation and MOV will be bypassed. This protection strategy will be adopted in UHV series compensation system.

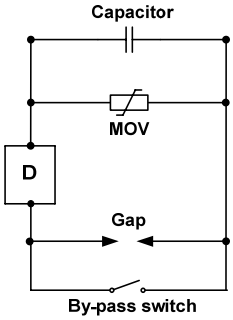


Fig.1. The basis configuration of series compensation protected by MOV, spark gap and by-pass switch

When a line occurs single-phase ground fault, second arc current and recovery voltage of the faulty point should be limited to low level[1]. In this way, the second arc can extinguish by itself and ensures single phase reclose. But series compensation and its protections such as MOV, spark gap and by-pass switch, make the problem of second arc self-extinguishing more complicated. The research concentrated in second arc current of series compensated transmission lines has been carried out in domestic and foreign country. As a result, the linkage measurement is proposed to be taken, which is while line protection monitors single-phase fault and commands line breaker to trip, by-pass switch of fault-phase series compensation is commanded to be closed.

This paper uses EMTP to analyze the influence of second arc during single-phase ground fault and the characteristics of second arc under linkage measure after installation of series compensation on Changzhi-Nanyang-Jingmen UHV line.

II. CHANGZHI-NANYANG-JINGMEN UHV AC SYSTEM CONDITION

The system configuration of Changzhi-Nanyang-Jingmen UHV AC demonstration project of China in 2012 is shown in Fig. 2. 1000kV bus voltage, transmission power, line length, and shunt reactor capability have been marked in the figure.

Changzhi-Nanyang and Nanyang-Jingmen lines have been installed 40% fixed series compensation. Series compensation of Changzhi-Nanyang line has been installed on both sides of the line, and series compensation of Nanyang-Jingmen line is focused on Nanyang side as shown in Fig. 1.

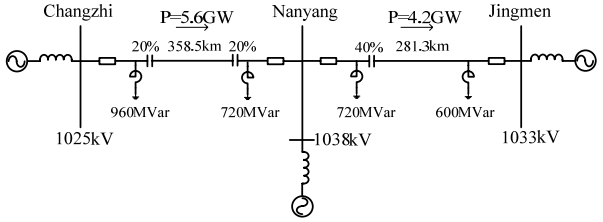


Fig.2. The sketch of Changzhi-Nanyang-Jingmen UHV AC system

III. POWER FREQUENCY COMPONENT OF SECOND ARC CURRENT AND RECOVERY VOLTAGE

Power frequency components of second arc current and recovery voltage during single phase reclosing, are shown under the two situations of faulty-phase series compensation with or without bypassing respectively by Tab. 1 and Tab.2 In the two tables, Lcn represents Changzhi-Nanyang line, and Lnj represents Nanyang-Jingmen line.

Conclusion can be drawn from the comparision of Tab. 1 and 2 that fault-phase series compensation with or without bypassing have little effect on power frequency components of secondary arc current and recovery voltage.

TABLE I

UNDER THE SITUATIONS OF FAULTY-PHASE SERIES COMPENSATION WITHOUT BYPASSING, POWER FREQUENCY COMPONENT OF UHV LINES' SECONDARY ARC CURRENT AND RECOVERY VOLTAGE

lines name	maximum recovery voltage/kV		maximum secondary arc current/A	
	head side	end side	head side	end side
Lcn	140.3	66.0	26.8	12.2
Lnj	95.5	61.5	13.3	8.6

TABLE Ⅱ

UNDER THE SITUATIONS OF FAULTY-PHASE SERIES COMPENSATION BYPASSING, POWER FREQUENCY COMPONENT OF UHV LINES' SECONDARY ARC CURRENT AND RECOVERY VOLTAGE

lines name	maximum recovery voltage/kV		maximum secondary arc current/A	
	head side	end side	head side	end side
Lcn	130.5	62.1	27.5	12.7
Lnj	89.3	53.2	13.5	7.8

IV. TRANSIENT OF SECOND ARC CURRENT AND RECOVERY VOLTAGE

When single-phase ground fault occurs in line with series compensation installed, and short-circuit current flowing through series compensation is too little that its protection fails to operate, and series compensation is not bypassed. Residual charge on series compensation discharges through a low-frequency oscillation circuit composed of series compensation, shunt reactor and arc resistor of short-circuit point as shown in Fig. 3. This action significantly increases low frequency component to second arc and recovery voltage, and extends extinguishing time of second arc, which may lead to failure in single phase reclose. So it is very necessary to research the transient of second arc current and recovery voltage for a line with series compensation.

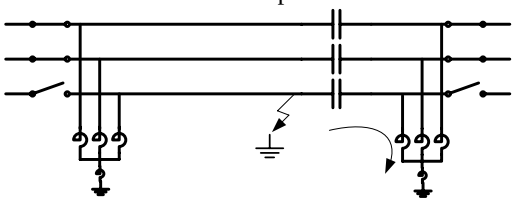


Fig.3. The low-frequency oscillation circuit of series compensated transmission system on the situation of single phase ground fault

A. Research condition

In this paper, transient characteristics of UHV lines' second arc current and recovery voltage, are analysed under the following three operation modes of series compensation, when single-phase ground fault occurred along Changzhi-Nanyang and Nanyang-Jingmen line.

1) Series compensation do not bypass, expressed as SC not bypassing in the following waveforms.

2) Series compensation permits bypass under consideration of series compensation protections such as MOV, spark gap and by-pass switch in Fig. 1, expressed as SC permitted bypass in the following waveforms. Under this condition, if the current or energy of MOV reaches the setting value, spark gap will be forced to trigger and by-pass switch to close. The fault-phase series compensation and MOV will be bypassed.

3) A linkage measure is added that by-pass switch of fault-phase series compensation is commanded to be closed while line protection monitors single-phase fault and commands line breaker to trip, expressed as SC linkage with breaker in the following waveforms.

Faulty timing: single-phase ground fault occurs at 100ms, followed by faulty-phase breakers of line's two sides trip at 150ms, finally the fault disappears at 200ms. Under the linkage measure, fault-phase series compensation is bypassed after fault occurring 20ms.

Different fault points along Changzhi-Nanyang and Nanyang-Jingmen line are showed by Fig. 4 and Fig. 5 respectively.

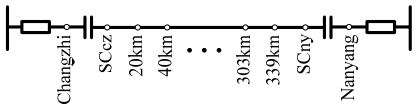


Fig.4. Faulty points along Changzhi-Nanyang line

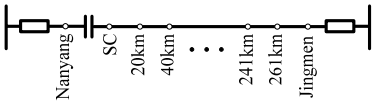


Fig.5. Faulty points along Nanyang-Jingmen line

Arc model: before line circuit breakers opening, primary arc is simulated as 1ohm resistor; after they opening, second arc is simulated as 100ohm resistor by using EMTP.

B. Second arc current of Changzhi-Nanyang line

When the fault happens on different faulty points along Changzhi-Nanyang line, the max second arc current after two side breakers tripping 0.5s, is shown in Fig. 6. Series compensation is abbreviated as SC in the figure.

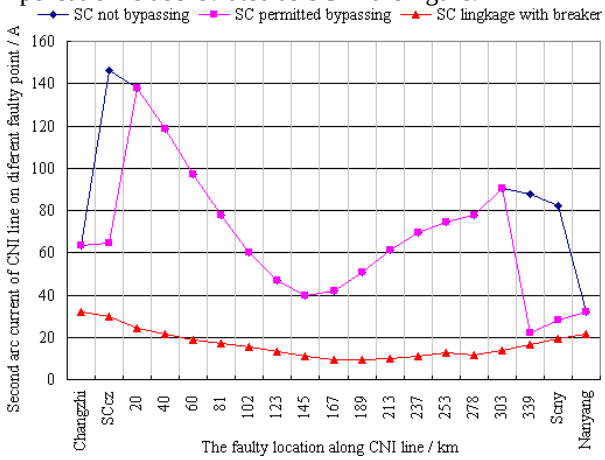
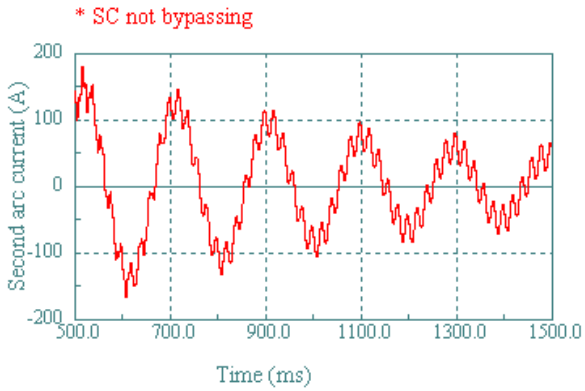
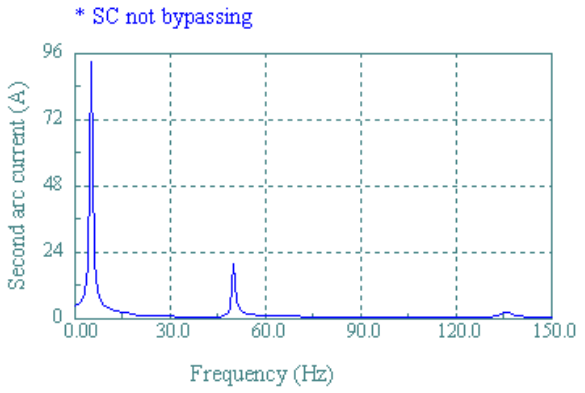


Fig.6. The max second arc current of Changzhi-Nanyang line after two side breakers tripping 0.5s

When the fault happens on line side of Changzhi series compensation (SCcz fault point), second arc current waves (time and frequency domain) of faulty point under three operation modes of SC after two side breaker tripping 0.35s, is showed by Fig. 7 to Fig. 9.

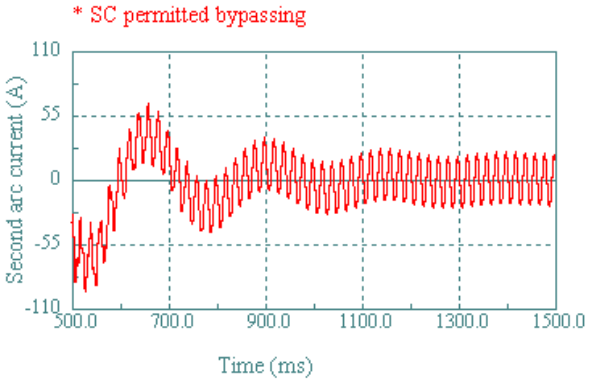


(a) Time domain analysis

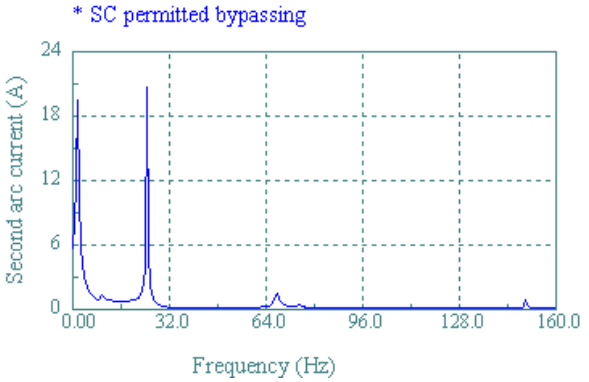


(b) Frequency domain analysis

Fig.7. When the fault happens on SCcz point and SC without bypassing, second arc current wave after two side breaker tripping 0.35s

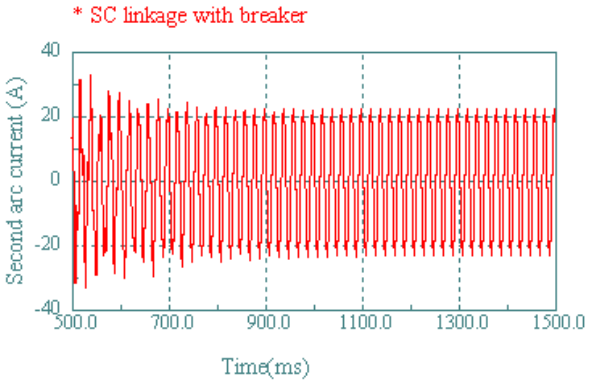


(a) Time domain analysis

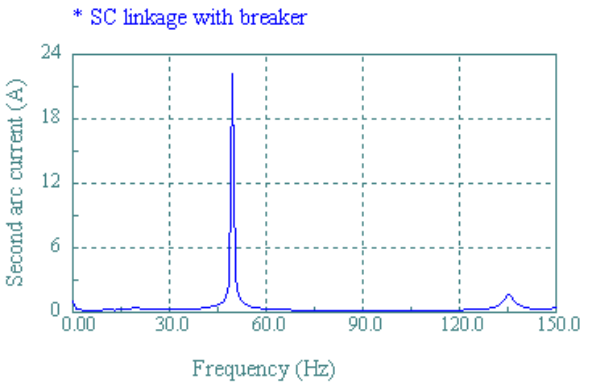


(b) Frequency domain analysis

Fig.8. When the fault happens on SCcz point and SC with bypassing, second arc current wave after two side breaker tripping 0.35s



(a) Time domain analysis



(b) Frequency domain analysis

Fig.9. When the fault happens on SCcz point and SC links with breaker, second arc current wave after two side breaker tripping 0.35s

From above results, the conditions about Changzhi-Nanyang line can be summarized:

1) On the condition of fault-phase series compensation without bypass, second arc current on all faulty points is quite large except for the point of line end. And most fault-point second arc current is over 60A. In Fig. 7, second arc current on SCcz point is 5.1Hz low-frequency oscillatory wave, of which characteristics are slow-decaying and fewer-zero, with result of disadvantage to second arc self extinguishing. 0.5s after line breaker tripping, the peak of current is 146.1A. And second arc can not self extinguish.

2) Considering the action characteristics of series compensation's protection, series compensation permits bypassing when the energy or current of MOV exceeds setting value. Short-circuit current is high only on the fault location near Changzhi or Nanyang series compensation, thus the protection of fault-phase series compensation near faulty point can operate to make fault-phase series compensation bypass. And second arc current reduces little. But on other locations, series compensation's protection can not operate since the current is still large, which is same to series compensation without bypassing. In addition, even if series compensation near faulty point can be bypassed, its contralateral series compensation can not. So the second arc current remains a higher proportion of low-frequency harmonic component as showed in Fig. 8. For example, the peak current on SCcz faulty point reduce to 64.8A from 146.1A after line breaker tripping 0.5s. But the current is still high that second arc can not self extinguish either.

3) Under the linkage measure, that series compensation protection links with line breaker, fault-phase series compensation of both sides can bypass. So low-frequency harmonic component of second arc current decays quickly as showed in Fig. 9. After line breaker tripping 0.5s, the maximum current on different location along the line does not exceed 32.2A, which is obviously lower than series compensation without bypass.

C. Second arc current of Nanyang-Jingmen line

When the fault happens on different points along Nanyang-Jingmen line, the maximum second arc current after two side breaker tripping 0.5s, is shown in Fig. 10.

When the fault happens on the position of 80km from SC, second arc current waves (time and frequency domain) of fault point under three operation modes of SC after two sides breaker tripping 0.45s, is shown in Fig. 11 and Fig. 12.

From above results, the conditions about Nanyang-Jingmen line can be summarized:

1) On the condition of fault-phase series compensation without bypass, second arc current on all fault points is quite large, exceeding 60A. In the Fig. 11, second arc current on the fault point of 80km from SC is 6.1Hz low-frequency oscillatory wave. After line breaker tripping 0.5s, the peak current is 89A. And second arc can not self-extinguish.

2) Considering the action characteristics of series compensation's protection, short-circuit current is high only on the fault location near Nanyang series compensation. So that the protection of fault-phase series compensation can operate to make fault-phase series compensation bypass. And second arc current reduces obviously to the level that equal to series compensation linking with breaker. But on other locations, series compensation's protection can not operate since second current is still large as showed in Fig. 11, which is same to series compensation not bypassing.

3) Under the linkage measure, fault-phase series compensation can bypass. So low-frequency harmonic component of second arc current decays quickly as showed in Fig. 12. After line breaker tripping 0.5s, the maximum current on different locations along the line does not exceed 15.1A, which is obviously lower than series compensation without bypassing.

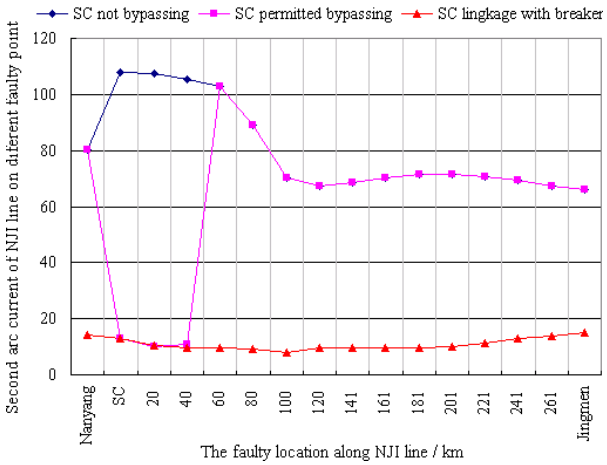
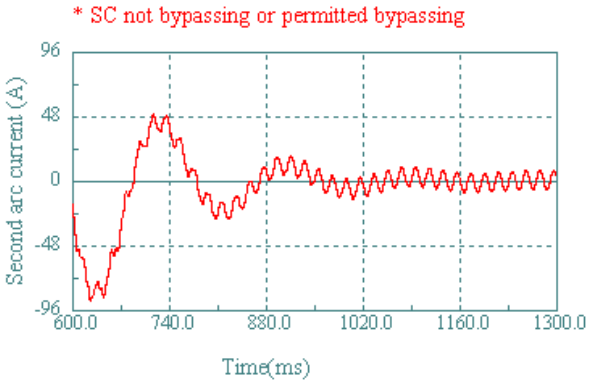
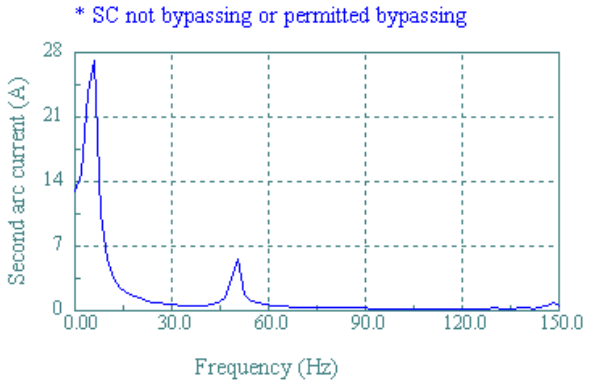


Fig.10 The maximum second arc current of Nanyang-Jingmen line after two sides breaker tripping 0.5s

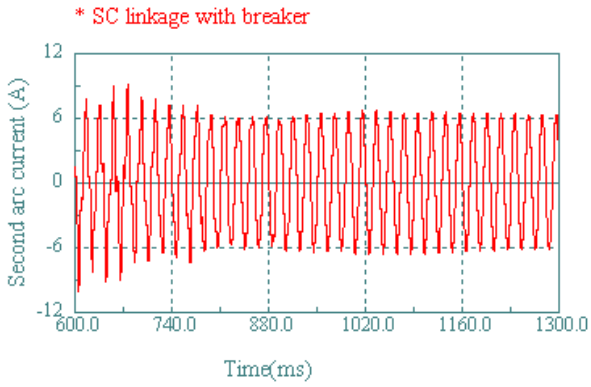


(a) Time domain analysis

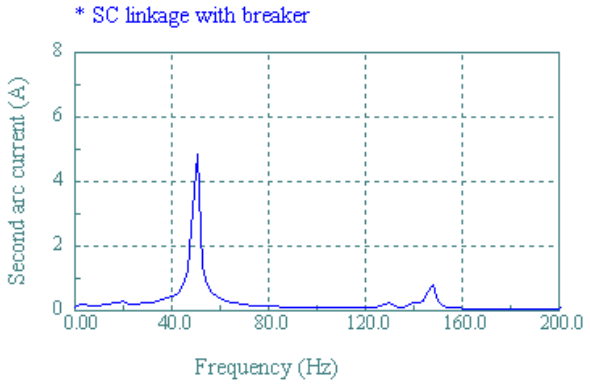


(b) Frequency domain analysis

Fig.11. When the fault happens on the position of 80km from SC and SC is not bypassing, second arc current wave after two sides breaker tripping 0.45s



(a) Time domain analysis



(b) Frequency domain analysis

Fig.12. When the fault happens on the position of 80km from SC and SC links with breaker, second arc current wave after two sides breaker tripping 0.45s

D. Recovery voltage

After second arc extinguishing, residual charge of fault phase and the coupling of non-fault phases make fault point recover voltage. Series compensation will increase low frequency transient component to the voltage, which is disadvantageous to second arc self extinguishing.

Take Nanyang-Jingmen line as an example , the influence of series compensation to recovery voltage, is researched as follows.

When fault-phase series compensation does not and links with line breaker, the maximum recovery voltage on different fault points along Nanyang-Jingmen line after second arc extinguishing, is calculated as showed in Fig. 13. And the waves of recovery voltage on line head are showed by Fig. 14 and Fig. 15. Then the following conclusions can be drew:

1) On the condition of fault-phase series compensation without bypassing, its residual charge makes recovery voltage higher than series compensation bypassing under linkage measure.

2) Recovery voltage of series compensation without bypassing, is a beating wave which is same to series compensation bypassing. But even it has a certain proportion of low frequency component as a result of series compensation. So recovery voltage decays slowly. For example, the frequency of recovery voltage is 4.1Hz as shown in Fig. 14. Whereas there is no this low frequency component on the condition of series compensation linking with line breaker as shown in Fig. 15.

Summarily, fault-phase series compensation will increase low frequency component to recovery voltage and slow down its decay rate. Linkage measure should be adopt to make the series compensation bypass.

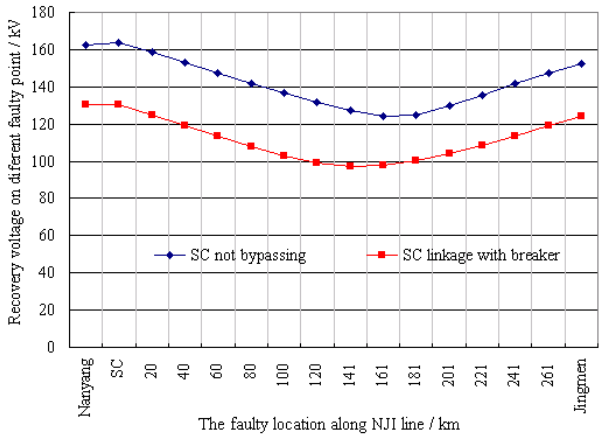
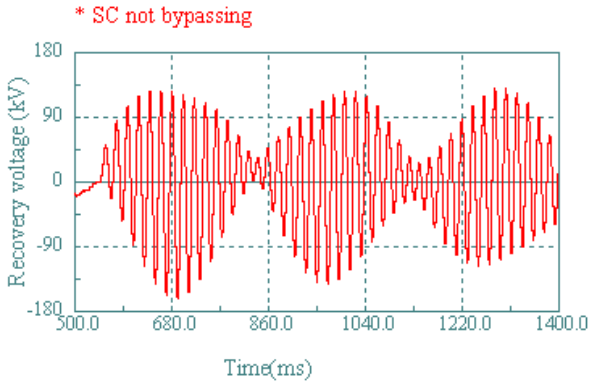
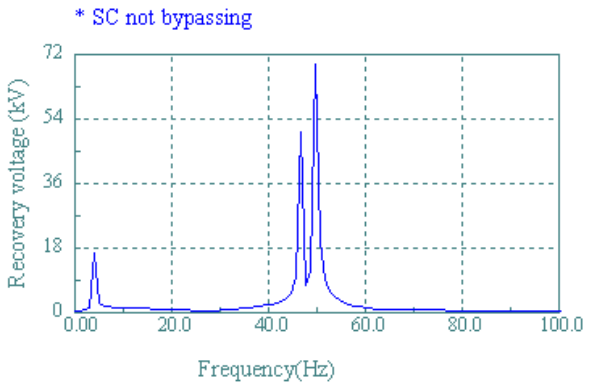


Fig.13 The maximum recovery voltage along Nanyang-Jingmen line after second arc extinguishing

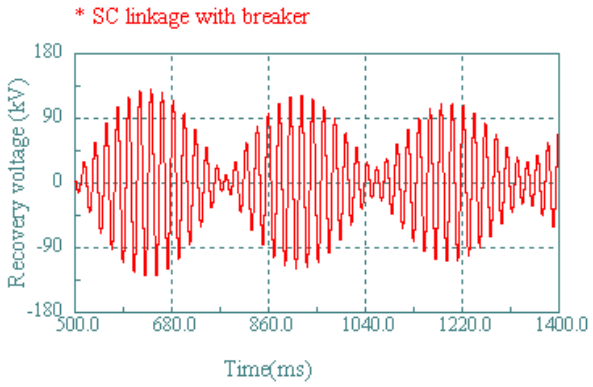


(a) Time domain analysis

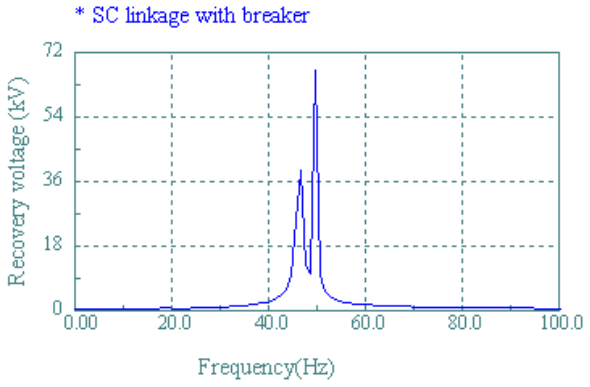


(b) Frequency domain analysis

Fig.14. When SC is not bypassing, recovery voltage wave of Nanyang-Jingmen line head after second arc extinguishing



(a) Time domain analysis



(b) Frequency domain analysis

Fig.15. When SC links with breaker, recovery voltage wave of Nanyang-Jingmen line head after second arc extinguishing

E. Sensitivity analysis for different compensation level

Different compensation level of series compensation has effect to transient of second current and recovery voltage when SC is not bypassed. Take Nanyang-Jingmen line as an example, sensitivity analysis is researched as follows.

When the fault happens on the position of 80km from SC, second arc current waves of fault point under series compensation degree of 20%, 40% and 60% after two sides breaker tripping 0.45s, is shown in Fig. 16.

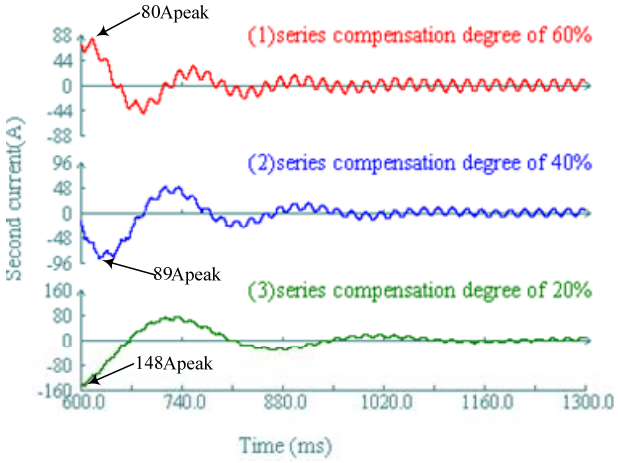


Fig.16. When the fault happens on the position of 80km from SC and SC is not bypassing, second arc current waves after two sides breaker tripping 0.45s

In the figure, second arc current under the series compensation degree of 20%, 40% and 60%, are about 2~8Hz low-frequency oscillatory waves. The lower series compensation degree is, the lower frequency is and the slower the second current decays. So the second arc current under the series compensation degree of 20% is larger than other conditions, which reaches to 148Apeak after two sides breaker tripping 0.45s.

But on the condition of series compensation linking with line breaker, the second current has no low frequency transient component on any compensation degree. Because three-phase series compensations have been bypassed during single phase reclosing.

V. CONCLUSIONS

Series compensation installed on UHV line in Changzhi-Nanyang-Jingmen UHV AC demonstration project of China, increases low frequency component to second arc current and recovery voltage when single phase ground fault occurs. It has characteristics of slow-decaying and fewer-zero, which are disadvantageous to second arc self extinguishing.

Although the protection of series compensation can operate to make series compensation bypass on some fault locations, only the series compensation near fault point can be bypassed and its contralateral series compensation still can not do so. And on the location of small short-circuit current, the series compensation can not be bypassed either. There will be a problem of second arc extinguishing. So a measure must be taken.

Under linkage measure that series compensation protection links with line breaker, fault-phase series compensation of two sides can both bypass. So low-frequency harmonic component of second arc current and recovery voltage decay quickly. After line breaker tripping 0.5s, the maximum current on different location along the line can be limited to a lower level, which is obviously lower than series compensation without bypass.

Summarily, UHV series compensated transmission line should take linkage measure to limit second arc and recovery

voltage during single phase ground fault in order to make single phase reclosing success.

VI. REFERENCES

[1] Cao Rongjiang, Gu Nihong, Sheng Yong. The Simulation Research on Secondary Arc Extinction Characteristics in Power System [J]. Proceedings of the CSEE, 1996, 16(2): 73-78 (in Chinese).

[2] Zhou Xiaoxin,Guo Jianbo, Lin Jiming, Gu Shouyuan . Power System Thyristor Control Series Compensation [M] . Beijing : Science Publishing House, 2009 (in Chinese).

[3] Lu Wei, Jin Xi. Secondary Arc in FSC Transmission Lines and Its Restraining Measure [J]. High Voltage Engineering, 2007, 33(7): 49-51 (in Chinese).

[4] Niu Xiaomin, Wang Xiaotong, Shi Wei, Wang Qiping. Secondary Arc Current and Recovery Voltage of Series Compensation Line [J]. Power System Technology, 1998, 22(9): 9-12 (in Chinese).

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