# HARMONIC ANALYSIS AND SIMULATION RESEARCH OF 10KV SERIES REACTOR FAILURE

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## ABSTRACT

*Taking the series reactor in 10kV cascaded capacitor bank of a typical 110kV substation A as an object, and aimed at the burning fault happened when the reactor was in operation, this paper made a concrete analysis, combining theory with practice. Firstly the Power quality tracking test on 10kV bus installed the capacitor bank has been taken. Then based on the actual testing data and resonant amplification theory the reactor failure was analyzed theoretically. Finally, using simulation software PSCAD/EMTDC, the simulation model of substation A and power load was built and the simulation results verified that the 10 kV capacitor bank of substation A exists harmonic amplification effect. So the harmonic amplification effect is the main reason caused series reactor failure.*

## KEY WORD

***cascaded capacitor bank；series reactor；harmonic monitoring；resonant amplification；PSCAD***

## INTRODUCTION

The 10kV cascaded capacitor bank is widely installed as the main equipment to regulate reactive power and voltage in substations[1]. With power grid development, the number of groups and capacity of power capacitor rapidly grew. In addition to capacitors, the 10kV cascaded capacitor bank also includes a group of series reactor to reduce switching current and suppress possibly harmonic resonant [2][3].

Substation A totally has 3 units of 63MVA capacity transformer, transforming 110kV to 10kV. The 10kV bus is divided into the # 1 bus, the # 2A bus, the 2B bus and the # 3 bus, respectively providing electricity to F1 ~~F45 feeders. In addition, each bus is separately configured with two groups of cascaded capacitor bank, whose capacity is 6000kVar and the reactance rate is 6%. Since substation A was put into operation, the series reactor in capacitor bank has burned several times in the past few years.

To find the cause of series reactor failure, this paper firstly took several power quality tracking test to master bus voltage and current. Then the testing data showed that the 5th and 7th harmonic current of the bus exceed standards, and the maximum value of bus voltage and harmonic current were much higher than the mean value and the 95% probability value. In addition, harmonic voltage and current spike appears at a specific moment. Combined with the capacitor harmonic amplification theory, modeling and simulation, the 3rd and 4th harmonic pollution generated amplification even resonance is the main reason of series reactor failure.

## FIELD POWER QUALITY MONITORING AND ANALYSIS OF TESTING DATA

This paper has taken three times of field power quality measurements on 3 main transformer 10kV bus, 110kV bus, and some of the feeders in substation A. Test results:

1) The harmonic voltage 95% probability value of the bus is in compliance with standards, but maximum value has an apparent peak, which is far above average. The initial judgment is that this peak caused by capacitor switching.

2) There are high-amplitude band before the harmonic peak, which may be triggered by the capacitor repeated switching or resonance when capacitor is switched.

3) The harmonic current of #2 bus and corresponding feeders have exceeded standards.

4) The harmonic voltage abnormally rose when capacitor was put into operation. It is reasonable to infer that capacitor switching is likely to cause resonance.

5) From the current testing results, substation A exists 2, 3, 4, 5, and 7 times harmonic source, and its capacitor group configuration can't prevent 4 times harmonic and below resonance. So the reactor failure of substation A mainly come from 2, 3, 4 times resonance.

Some figures of measurement results are shown as follows. The voltage and current THD trend measured on #3 bus are shown in Fig.1 and Fig.2. As can be seen, the bus not only appeared apparent harmonic voltage peak, but also has high-amplitude band before the peak. The harmonic current also appeared apparent peak.

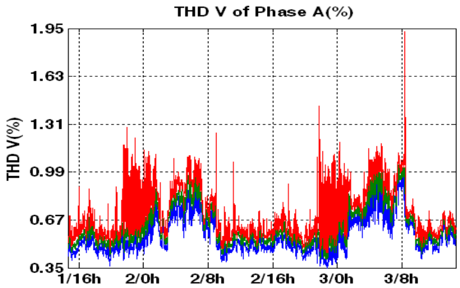


Fig. 1 The voltage THD trend measured on #3 bus

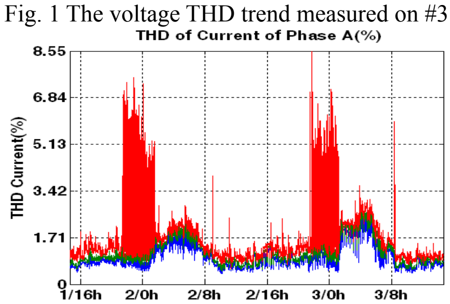


Fig. 2 The current THD trend measured on #3 bus

Fig.3 shows the 2, 3 and 4 harmonic voltage trend on feeder 24, as can be seen the 2, 3 and 4 times harmonic voltage has apparent peak in larger section, especially the 4 time harmonic voltage. Combined with Fig.1 and Fig.2, the bus voltage THD peak may be closely related to the 4 time harmonic voltage on feeder 24.

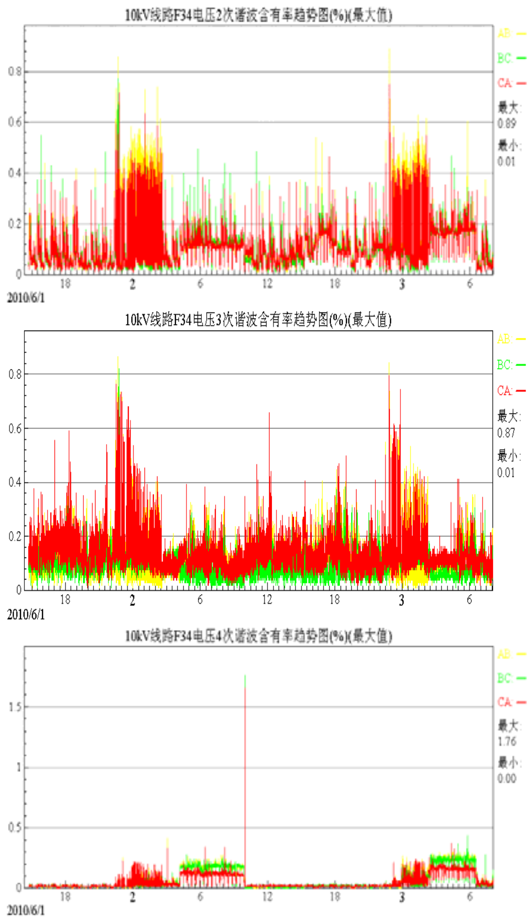

Fig. 3 The 2, 3 and 4 times harmonic voltage trend measured on feeder 24

## RESONANCE THEORY ANALYSIS

The harmonic sources in power system are mainly current sources. The load of harmonic sources includes the supply system and all users.

### One group of running capacitor bank

As shown in Fig.4, taking one running capacitor bank and the main system as an example, the basic principle of capacitor caused harmonic current amplification is briefly explained.

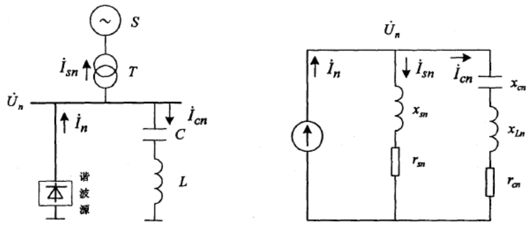

Fig. 4 Resonance analysis circuit

According to substation A, its capacitor capacity is 6000 kVar and series reactor rate is 6%. In the minimum operation mode, the short circuit capacity is 246.26 MVA.

If current type harmonic source contains n times harmonic component, the relationship between the harmonic current source and harmonic current of capacitor branch is [5][7][8]:

$$\mathrm{Icn} = \frac{nXs}{nXs + nX_L - Xc/n} In = \frac{Xs}{Xs + X_L - Xc/n^2} In \quad (1)$$

The harmonic number of parallel resonance is :

$$n_{r2} = \sqrt{\frac{X_C}{X_S + X_L}}, \quad n_{r2} = 3.4429 \quad (2)$$

The harmonic number of series resonance is :

$$n_{r1} = \sqrt{\frac{X_C}{X_L}}, \quad n_{r1} = 4.0825 \quad (3)$$

Bus harmonic voltage is : $Un = ji_n \dfrac{nXs(X_L - Xc/n^2)}{Xs + X_L - Xc/n^2}$ ,

$$\alpha = \frac{X_L - Xc/n^2}{Xs} \quad (4)$$

When $1 + \alpha = 0$, $n = nr2 = \sqrt{\dfrac{X_C}{X_S + X_L}}$, capacitor, system and series reactor occur parallel resonance, harmonic current is amplified to maximum value, which is related to the resistance of the circuit. Meanwhile, when the series reactor's reactance is bigger, the resonance harmonic number is lower, which means series reactor can inhibit lower times harmonic resonance.

Series resonance number in circuit is:

$$n_{r1} = \sqrt{Xc/X_L} = 1/\sqrt{k} \quad (5)$$

k is reactance rate.

When $n<n_{r1}$, capacitor branch is capacitive, which may produce harmonic amplification with system inductance; When n>nr1, capacitor branch is inductive, which will not produce harmonic amplification in parallel with system inductance.

So in the situation of one running capacitor bank, the 2nd, 3rd, 4th harmonic current will not be seriously amplified.

## Two group of running capacitor bank

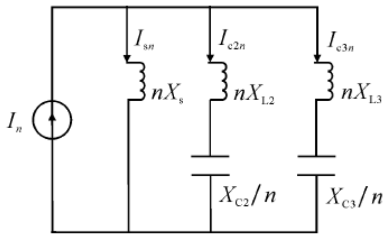


Fig. 5 Resonance analysis circuit

As shown in Fig.5, when the current type harmonic source contains n time harmonic current, then the relationship between the harmonic current source and harmonic current of each capacitor branch is:

$$I_{c2n} = \frac{X_2'}{X_2' + nX_{L2} - X_{C2}/n} In \quad (6)$$

$$X_2' = nX_S // (nX_{L3} - X_{C3}/n) \quad (7)$$

Equivalent capacitor group and system side produce parallel resonance, its parallel resonance number is:

$$n_1 = \sqrt{\frac{X_C'}{X_S + X_L'}}, \quad n_1 = 3.0327 \quad (8)$$

It is very close to 3 times resonance. So in the situation of two groups of running capacitor bank, the 3rd harmonic current in capacitor branch can be seriously amplified.

Based on resonance theory analysis and substation A electrical structure, when running one group of capacitor, capacitor branch series resonance is close to 4 times, and parallel resonance with system inductance is 3.5 times. If operation parameters change, it may cause 3 or 4 times resonance.

However, when running two groups of capacitor, capacitor branch and system parallel resonance is very close to 3 times, so the possibility of 3 times resonance is very high.

From the grid structure and capacitor group configuration in substation A, it is easy to produce amplification because of 3, 4 times harmonic pollution, which may be the internal cause of the reactor failure.

# RESONANCE SIMULATION ANALYSIS

To verify the theoretical analysis, this paper built simulation model of substation A and power load and analyzed the transient process based on PSCAD/EMTDC.

## Simulation Model

According to the electrical wiring structure of substation A, the simulation model is built as shown in Fig. 6. The capacity of #2 transformer is 63MVA, and the impedance is 16%. Low voltage bus involves #2A bus and #2B bus, which are connected with one group capacitor bank and several feeders respectively. The current source added to the load side represents harmonic current injected by polluted load.

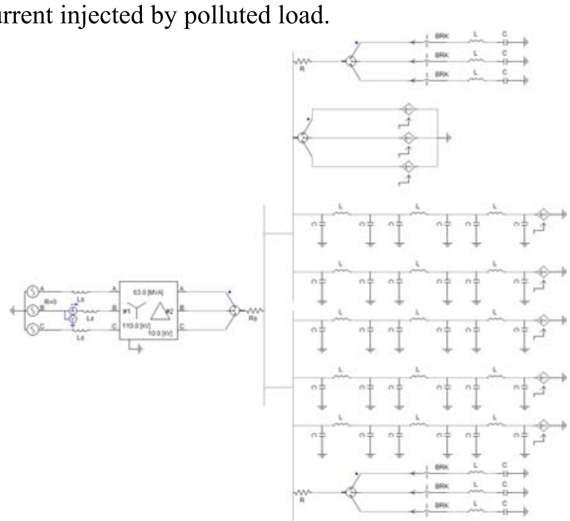

Fig. 6 Simulation model of one transformer in substation A

## The simulation of resonance of capacitor bank

In the case of the bus with each harmonic, respectively closing the two capacitor groups in 2 seconds and 3 seconds, and then simulation results are obtained as follows:

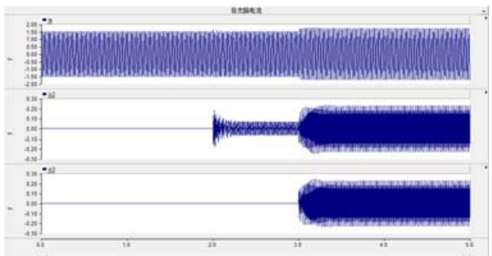

Fig.7 The current waveforms of the system, the capacitor bank 1 and capacitor bank 2

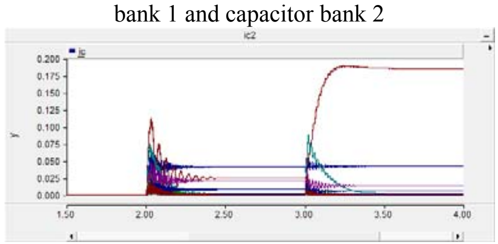


Fig.8 Current amptitude of each times harmonic of the capacitor branches

From Fig.7 and Fig.8, when one group of capacitor bank is running, the harmonic current has no serious amplification. When two groups of capacitor bank are running, the 3rd harmonic current (red curve) was severely amplified.

Based on theoretical analysis, the harmonic number of series resonance is larger than 4 times and the harmonic number of parallel resonance is between 3.3 to 3.5 times. So the fourth harmonic current has amplification effects on the capacitor group. The greater reactance rate is, the closer to 4 times in series resonance and the closer to 3 times in parallel resonance. To a certain extent, it may make harmonic resonance occur. When the reactance rate becomes smaller, the possibility of series resonance and parallel resonance is increased. When the capacity of the capacitor reduced to a certain extent, the capacitor bank has serious amplification on 4th harmonic currents.

In the case of two groups of running capacitor, the number of parallel resonance of capacitor group and the system is close to 3 times, so the capacitor bank current of 3rd harmonic increases rapidly.

## CONCLUSION

Based on three times field power quality test, the theoretical and simulation analysis, the following conclusions can be drawn:

(1) The harmonic of substation A has the nature of strongly intermittent, sudden and short-term high-amplitude.

(2) It is prone to enlarge the $3^{rd}$ and $4^{th}$ harmonic pollution even resonance based on theoretical and simulation analysis of electrical structure of substation A.

(3) The main reason for series reactor failure in substation A is: the resonance of capacitor banks in certain circumstances of intermittent $3^{rd}$ and $4^{th}$ harmonic source in user side.

In summary, the capacitor structure of substation A and users' harmonic pollution caused the reactor failure. Only harmonic control of user side will not surely avoid the reactor burned accident. Therefore, it is recommended to change the reactance rate parameters of capacitor bank, and apply special customized capacitors and reactors. Meanwhile, the active power filter should be installed before a reactive power compensation device is put into practice.

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