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Research Article

Research on overvoltage suppression of interrupting no load transformer

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Abstract

In the process of power system operation, it is normal to interrupt no load transformer, reactor and no load motor. Switching those inductive loads will give rise to high amplitude overvoltage. With the example of a steel mill's refining furnace transformer, this paper covers the basic principle of the overvoltage formation, introduces the advantages and disadvantages of the resistance-capacitance absorbing device and rectifier bridge device. On base of the above analysis, this paper puts forward a mixed device to suppress overvoltage of interrupting no load transformer. Moreover, simulation has been worked with ATP-EMTP, the results show that the device can greatly reduce the overvoltage and improve the reliability of the system. At last, the effectiveness and feasibility of the presented device are verified by the experiment..

Key words: overvoltage; transformer; suppressing measure; reliability

1. Introduction

The state increased investment in infrastructure projects in recent years, a number of submerged arc furnace have been built to promote the development of iron and steel enterprises. Most of those energy-intensive enterprises are using electric arc furnace, which would cause hidden troubles to the grid, such as line trips, equipment damages and overvoltage accidents. Among this, the overvoltage accident caused by using the vacuum breaker to cut off the arc furnace transformers is one of the most serious problems [1-13].

A lot of researches on overvoltage of interrupting no load transformer have been done, and many solutions have been put forward to suppress the overvoltage. Authors of [1] propose a way based on raise the insulation level of the transformer winding, and provide the adjustment range of the insulation level of the 35kV transformer winding. [2-3] restrains the overvoltage by MOV and resistance capacitance absorbing device and puts forward the principle to selecting the arrester model. Besides, it solves the matching problems of the resistance and capacitance parameters. In [4], a device which based on resistance capacitance absorbing device and rectifier bridge device in parallel with the secondary side of the transformer is presented. The simulation results show the effectiveness of this method in reducing the overvoltage.

The method of [1] can't fundamentally reduce the overvoltage, especially for the high voltage transformer. It is expensive and hard to raise the insulation level of the transformer winding. The device proposed in [2] is the most widely used method presently, but the effectively of this method is limited to some special transformers. Moreover, the transformer would be easily damaged when the faults occur in arrester or resistance-capacitance absorbing device. The system is not very reliable. [4] proposed a new method, but didn't give the match of the parameters and had no related experiments.

With the example of a steel mill's refining furnace transformer, this paper analyses the effects of restraining overvoltage of interrupting no load transformer by different devices, and proposes a mixed device to suppress overvoltage based on resistance-capacitance absorbing device and rectifier bridge device. This paper also gives the match of associated parameters, and verifies the effect by simulations and experiments. The results of the simulations and experiments show that this method can restrain the overvoltage and improve system reliability.

2. The formation mechanism of the overvoltage of interrupting no load transformer

There are two ladle furnaces in the steel mill: each one is connected to the 35kV bus by a transformer. The switch of the ladle furnaces is controlled by vacuum breaker. In order to restrain the overvoltage, the high voltage side of the transformer has been paralleled with arrester and resistance-capacitance absorbing device. However, the accident still happened for the arrester exploding in October 2010.

2.1 The line and transformer parameters

The input line of the ladle furnace is three-phase three-wire system, and the RMS of the line voltage is 35kV. Transformer model: HJSSPZ—28000/35, the rated capacity is 28MW，the rated voltage is 35kV, the no-load current is 0.48%, the no-load loss is 25.4kW, the load loss is 241kW, the short impedance is 9.31%. Fig. 2 is the circuit diagram of the furnace system.

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Fig. 1 The windings of the transformer was burned out

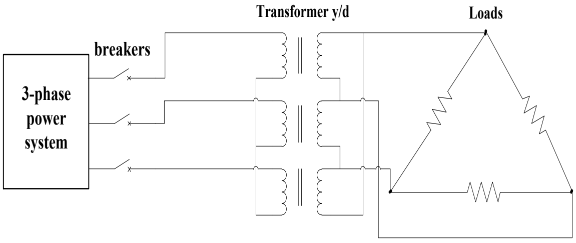


Fig. 2 Circuit diagram of the furnace system

2.2 The theoretical derivations

We know the circuit breaker should be able to cut off the short-circuit current of transformers, but the exciting current i_L is only 0.01%~1% of the short-circuit current. So when the breaker cuts off the exciting current, the arc is usually not extinguished at the time of the current zero-crossing. Because of its strong interruption ability of arc, $di_L/dt \to (-\infty)$. Then the induced voltage on the magnetizing inductance of transformer could reach to a large numerical. In fact, in the practical circuit, besides the magnetizing inductanceL_B, there is capacitance C_B in the transformer winding. According to the conservation of energy, when all of the magnetic field energy converts into static electricity energy, the voltage of the capacitor will be maximum U_{Bm} [5],

$$\frac{1}{2}C_B U_{Bm}^2 = \frac{1}{2}L_B I_0^2 + \frac{1}{2}C_B U_0^2 \tag{1}$$

That means the U_{Bm} could be

$$U_{Bm} = \sqrt{I_0^2 \frac{L_B}{C_B} + U_0^2} \tag{2}$$

When the current break at the peak of the exciting current, then

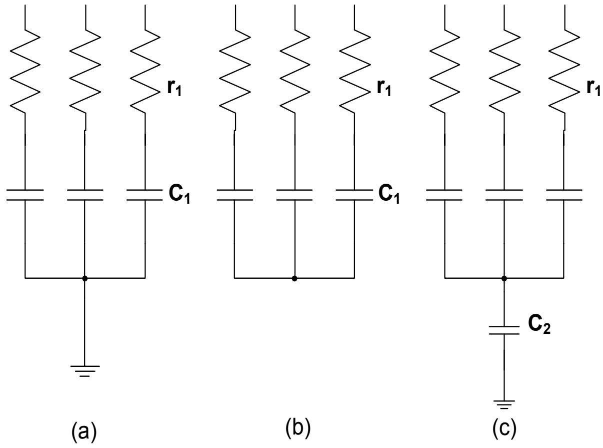
$$U_{Bm} = I_m \sqrt{\frac{L_B}{C_B}} \tag{3}$$

If the transformer didn't install any overvoltage restrain device, for the primary side capacitance to ground of the transformer is only 13.3nF, we could know that the primary side will produce a high amplitude overvoltage to ground by formula (3).

3. Restraining the overvoltage with resistance - capacitance absorbing device

3.1 The types and principle of different resistance-capacitance absorbing devices

The resistance-capacitance absorbing device can be classified into common model, neutral non-grounded model and double resistance-capacitance overvoltage protector. The structures are shown in Fig. 3.



(a) common RC protector (b) neutral non-grounded RC protector
(c) double RC overvoltage protector

Fig. 3 Three kinds RC protectors

(1) Common RC protector. The common model resistance-capacitance absorbing device is the most widely used device presently. And with reasonable resistance capacitance parameters selection, the peak value of the overvoltage would drop to 2 p.u. when operate the transformer. But this device has following disadvantages: 1) in neutral non-grounding system, the system should run normally when single-phase grounding fault occurs, but usually because of the large current caused by the RC protector the feeder circuit of system all trip; 2) in some small capacity power systems, the large current of the capacitance will make the switch trip. 3) in some power pollution heavier circuits, such as metallurgical and chemical factories, the resistances of the RC protector will burnout for the large proportion of high frequency component in the voltage waveform.

(2) Neutral non-grounded RC protector. As is shown in figure 3(b), the line to line voltage won't changes when single-phase grounding fault happens, so this kind RC protector won't cause switches trip and resistance burnout. But it just protect the oscillation between phases, the protection to ground is weak. So the circuit use this kind of RC protector would have a higher probability in happening overvoltage accidents than common model.

(3) Double resistance-capacitance overvoltage protector. Figure 3(c) is double resistance-capacitance overvoltage protector, C_1 is mainly protect the overvoltage between phases by absorb the energy stored in phases circuit; C_2 is mainly protect the overvoltage to ground. This method solve the problems of the current is too large and the resistance burnout. The result of the simulation show that chooses proper parameters of C_1 and C_2, the device could eliminate switching overvoltage effective [6].

3.2 The resistance-capacitance absorbing circuit of a ladle furnace transformer

The RC protector used in the transformer of the ladle furnace is common model, and R=100Ω,C=0.1μF. The transformer is equivalent to the multiple of the entrance capacitance of transformer and the field winding, the field winding consists of the resistance and the magnetizing inductance. Assuming that the vacuum breaker could force the no-load current from peak to zero, and the simulation of ATP shows that the greatest overvoltage is 2p.u..Fig. 4 is the simulation mode, and Fig. 5 is the overvoltage waveform of the primary side of the transformer.

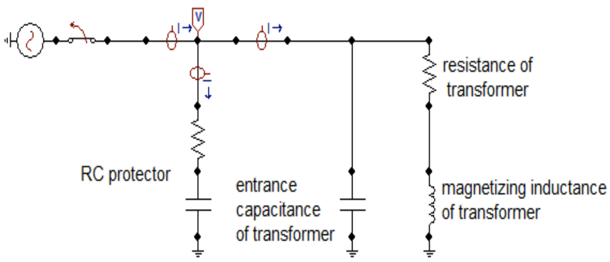


Fig. 4 The simulation mode of ATP

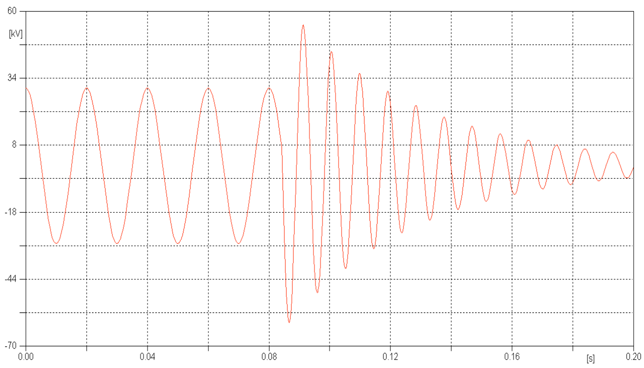


Fig. 5 The overvoltage waveform of the primary side of the transformer

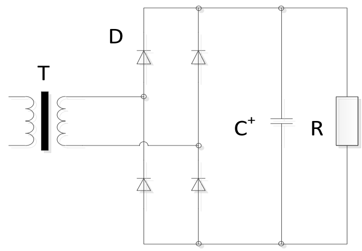
The result indicates that this type resistance - capacitance absorbing device could greatly reduce the overvoltage of interrupting no load transformer. But as previously stated, without reasonable measures to cooling, the resistance will burnout and explode in some cases. Then the transformer will lose protection, and the great overvoltage of interrupting transformer will cause damage to the transformer.

4 Restraining the overvoltage by rectifier bridge device

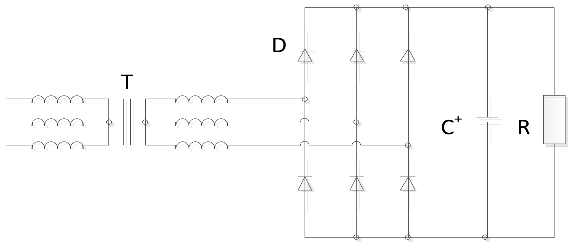
4.1 The principle of Rectifier Bridge device

To protect the transformer of the rated voltage is 6kV~35kV and low voltage side is 150 ~350V, except for arrester and resistance-capacitance absorbing device usually used in the primary side, there also install rectifier bridge and electrolytic capacitor of great capacitance in transformer's secondary[7]. The capacitor could absorb the energy when current break, and then restrain the overvoltage of high voltage side.

The principle circuit of the overvoltage restrain device with Rectifier Bridge is as Fig. 6 show. The main parts include the rectifier bridge D, electrolytic capacitor C and resistance R installed in low voltage side.



(a)single phase connection



(a)3-phase connection

Fig. 6 The principle circuit of the overvoltage restrain device with Rectifier Bridge

The advantage of this device is that it could not only restrain overvoltage effectively, but also won't cause switch trip and resistances burnout. In addition, the electrolytic capacitor could have great capacitance in low voltage with low price; this device could improve the reliability of the system.

4.2 The RC parameters of the rectifier bridge

The selection of RC parameters for the rectifier bridge has obvious effects on restraining overvoltage. The smaller the capacitor is, the less energy the device absorbs, then the result on retraining overvoltage will be not obvious. Besides, the greater the resistance is, the smaller the current is, and the energy the device absorbs will be less, too. What is shown in Table 1 is that the corresponding greatest overvoltage of the transformer's primary side to ground when R=0.5Ω, the capacitance of the rectifier bridge is different. Table 2 is that the corresponding greatest overvoltage of the transformer's primary side to ground when C=0.05F, the resistance is different.

Table 1. The greatest overvoltage of the transformer's primary side to ground when R=0.5Ω

Capacitance C（F）	0.5	0.05	0.005	0.0005
the greatest overvoltage of the transformer's primary side to ground（kV）	37.45	37.47	37.55	60.7

Table 2. The greatest overvoltage of the transformer's primary side to ground when C=0.05F

Resistance R（Ω）	0.05	0.1	0.5	5
the greatest overvoltage of the transformer's primary side to ground（kV）	33.76	33.8	37.6	112.76

According to table 1, when the resistance of the rectifier bridge is 0.5Ω, with the increasing of the value of the capacitance, the greatest overvoltage of the transformer's primary side to ground is decreasing, and when the capacitance's value reach to 0.05F, the effect of restrain the overvoltage change less. Consider the price and the effect of restrain the overvoltage, the capacitance is selected as 0.05F.From table 2 we can see when C=0.05F, with the increasing of the value of the resistance, the greatest overvoltage of the transformer's primary side to ground is increasing. But when the resistance is too small, the transient current of the diodes will be very large, so the resistance is selected as R=0.5Ω.

The shortcoming of this device is that compare to traditional electronic devices its lifetime and stability is more bad. Only use this device to restrain the overvoltage, the transformer will lose protection easily.

5. A mixed device composed of resistance-capacitance absorbing device and Rectifier Bridge

Due to use resistance-capacitance absorbing device or Rectifier Bridge absorbing device alone has their respective shortcomings; the author put forward that parallel the resistance-capacitance absorbing device at the transformer's primary side, and parallel the Rectifier Bridge device at the transformer's second side at the same time. That would not only further reduce the overvoltage value of the transformer, but also greatly improve the safety factor of the transformer. Table 3 and table 4 are the result of two devices use together when the parameters of the rectifier bridge are changed, but the parameters of the resistance-capacitance absorbing device are set as R=100Ωand C=0.1μF. Table 5 is the comparison of those three devices.

Table 3. The resistance of the rectifier bridge is 0.5Ω, the greatest overvoltage of the transformer's primary side to ground when change the capacitance of the rectifier bridge

Capacitance C（F）	0.5	0.05	0.005	0.0005
The greatest overvoltage of the transformer's primary side to ground（kV）	34.6	34.68	35.67	47.02

Table 4. The capacitance of the rectifier bridge is 0.05F, the greatest overvoltage of the transformer's primary side to ground when change the resistance of the rectifier bridge

Resistance R（Ω）	0.05	0.1	0.5	5
The greatest overvoltage of the transformer's primary side to ground（kV）	29.57	30.25	34.69	50.94

Table 5. The comparison of those three devices in restraining overvoltage

Device	The greatest overvoltage to ground（kV）	Reliability
Only install resistance -capacitance absorbing device at the transformer's primary side（100Ω，0.1μF）	61	Relatively high
Only install Rectifier Bridge absorbing device at the transformer's secondary（0.5Ω，0.05F）	37.47	Relatively low
Install both above	34.69	high

6. The experiment

6.1 The experiment platform

The equipment of the experiment: a three-phase voltage regulator, 3 resistances of 100Ω, 3 capacitances of 0.1μF, a resistance of 968Ω, a three-phase transformer, a three-phase rectifier bridge, a electrolytic capacitor of 0.05F, a resistance of 0.5Ω, a vacuum breaker, a current measure probe, an oscilloscope. Fig. 7 is the principle diagram of the experiment.

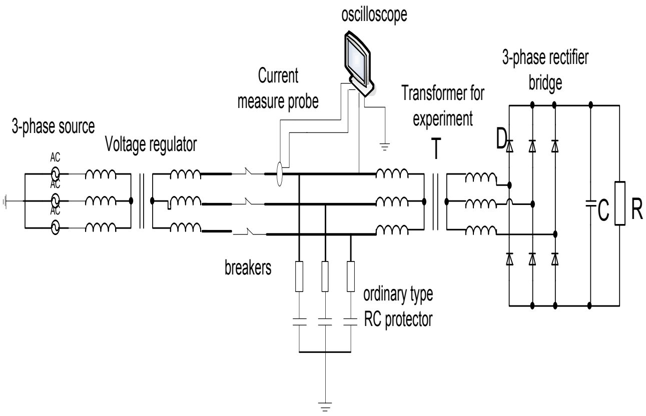


Fig. 7. The principle diagram of the experiment

6.2 The experimental results

(1) When the secondary side of the transformer is in no load, the overvoltage to ground of the primary side is 1.9 times. The experimental result is close to the theoretical analysis of 2 times. The measured voltage waveform is shown in Fig. 8.

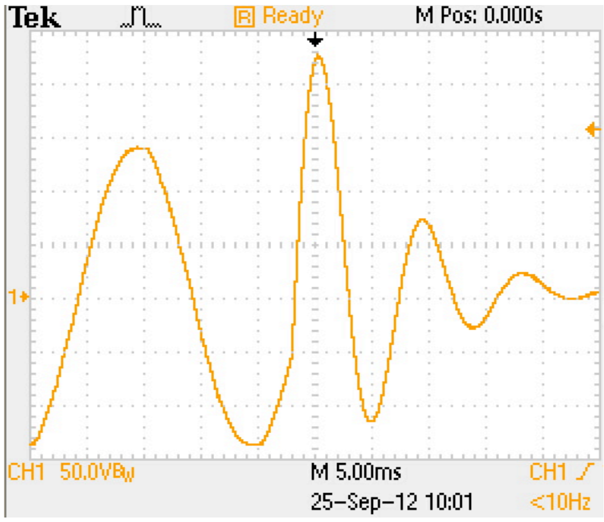


Fig. 8. The measured waveform of the overvoltage without Rectifier Bridge absorbing device

(2) When the Rectifier Bridge device parallels to the secondary side of the transformer, the overvoltage to ground of the primary side is 1.16 times. The experimental result is close to the theoretical analysis of 1.15 times. The resistance is 0.5Ω and the capacitance is 0.05F. The measured voltage waveform is shown in Fig. 9.

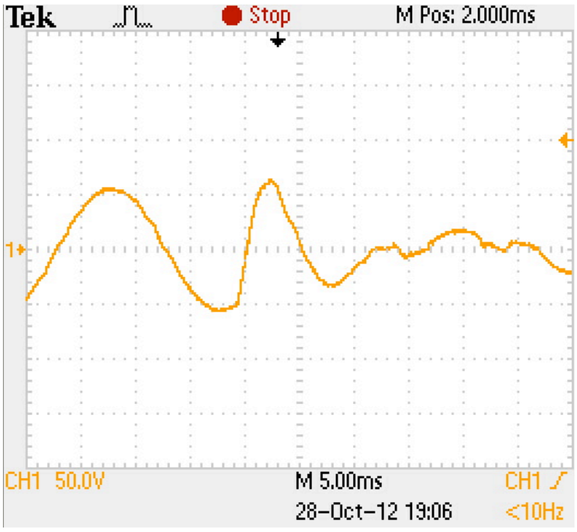


Fig. 9. The measured waveform of the overvoltage with both absorbing devices

7. Conclusions

1. Because of the chopping current caused by the vacuum breaker, the greatest overvoltage could reach 5 to 7 times of the rated voltage when cut off no load transformer.
2. Both the resistance-capacitance absorbing device and Rectifier Bridge absorbing device could greatly reduce the overvoltage, but they also have some deficiencies.
3. Use the resistance-capacitance absorbing device and Rectifier Bridge absorbing device at the same time, could not only further reduce the overvoltage value of the transformer, but also greatly improve the safety factor and reliability of the transformer.

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