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Analysis on Short Circuit Current Limiting Effect of Installing Small Reactance in 500kV Autotransformer's Neutral-point

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Abstract. For the condition that single-phase short circuit current exceeds three-phase short circuit current occurs on some of Shandong 500kV substations' 220kV bus, this paper studies the principle of limiting 500kV autotransformer's short circuit current by installing small reactance. Considering that installing small reactance at 500kV autotransformer's neutral point influences the zero sequence circuit, this paper suggests to configure independent relay protection on small reactance which aims at supervision the short circuit current and improving reliability. Protection setting for neutral-grounding small reactance is proposed. Simulation results and protection setting software show the effect of limiting short circuit current by installing small neutral-point reactance.

1. Introduction

With large number of 500kV substations putting into operation, the power system becomes more complex and closer connected, which causes the growing short circuit level in Shandong power grid. In 500kV power system, 750MW or 1000MW neutral-grounding autotransformers are widely used. Large numbers of grounding points in the power grid decreases zero sequence impedance, and single-phase short circuit current will exceed three-phase short circuit current in some of Shandong 500kV substation's 220kV bus. This will threaten the safety operation and system reliability of power grid[1].

Nowadays, methods of limiting short circuit current mainly includes: delaminating and districting operation; bus separate running; installing neutral-grounded small reactance; using high-impedance transformer; using series reactor and so on. Based on the actual operation and control situation of Shandong power grid, the first three categories are frequently used[2].



For the condition that single-phase short circuit current exceeds three-phase short circuit current in some of Shandong 500kV substation's 220kV bus, this paper illustrates the principle of limiting short circuit current by installing small reactance on the neutral-ground point. Meanwhile, in order to improve the reliability of relay protection after neutral-grounded by small reactance, an independent relay protection for the small reactance is configured and corresponding protection setting is proposed. The effectiveness of limiting short circuit current is validated by small reactance using in a 500kV substation and PSCAD simulation results.

2. Principle of Limiting Short Circuit Current by Installing Small Reactance on Autotransformer

2.1 Principle of Autotransformer

Autotransformer is widely used in Shandong 500kV power grid because of small size, high efficiency and material saving. At present, the autotransformer's capacity used in Shandong 500kV power grid is 750 MW or 1000 MW, the rated voltage is 525/230+2*2.5%/36, and the connection set is Yna0d11.

There is a common winding of the autotransformer's high voltage side and the medium voltage side so that electronic connection exists between high voltage winding and medium voltage winding. And the neutral point of the high and medium voltage side are connected together and grounded at the same point. In addition to the role of electromagnetic induction, power transmission of autotransformer depends on the direct conduction of electricity. The principle and connection diagram of autotransformer is shown in figure 1. \dot{I}_1 , \dot{I}_2 and \dot{I} are current of high voltage winding, medium voltage winding and common winding. k is the ratio of high voltage side and low voltage side.

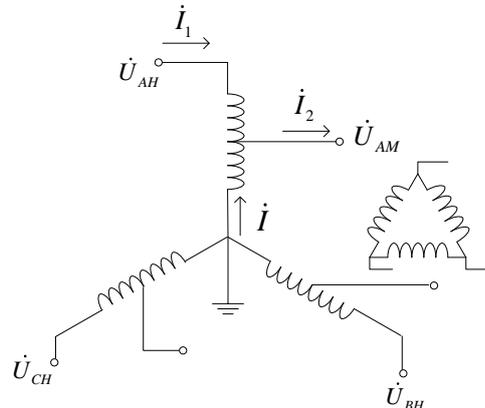


Figure 1. Principle and connection diagram of autotransformer

By analyzing the principle diagram of autotransformer, the relationship between high voltage side current and medium voltage side current is shown as follows:

$$\frac{\dot{I}_1}{\dot{I}_2} = \frac{1}{k} \quad (1)$$

The relationship between common winding current and medium voltage winding current is shown as follows:

$$\frac{\dot{I}}{\dot{I}_2} = \frac{1}{k} \cdot \frac{\dot{I}_2 - \dot{I}_1}{\dot{I}_1} = 1 - \frac{1}{k} \quad (2)$$

2.2 Zero Sequence Circuit of Autotransformer

2.2.1 Zero Sequence Circuit of Neutral-point Solid Grounded Autotransformer. When outside grounding fault occurs on medium voltage side of the autotransformer, zero sequence equivalent circuit of neutral-point solid grounded autotransformer is shown in figure 2.

X_{H0} , X_{M0} and X_{L0} are zero sequence impedance of high voltage side, medium voltage side and low voltage side. X_{SM0} and X_{SN0} are zero sequence impedance of the system, I_{10} and I_{20} are zero sequence current of high voltage side and medium voltage side. I_{ZX} is current of neutral-point small reactance.

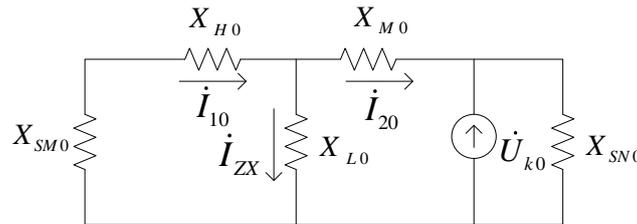


Figure 2. Zero sequence circuit of neutral-point solid grounded autotransformer

When grounding fault occurs at medium voltage side of the autotransformer, neutral-point small reactance current is calculated as following[3]. k is the ratio of high voltage side and low voltage side.

I_{10}' is the converted high voltage side current to medium voltage side.

$$i'_{10} = k i_{10} = \frac{X_{L0}}{X_{SM0} + X_{H0} + X_{L0}} \bullet i_{20} \quad (3)$$

$$\begin{aligned} i_{ZX} &= 3i = 3(i_{20} - i_{10}') \\ &= 3 \left[i_{20} - \frac{X_{L0}}{k(X_{SM0} + X_{H0} + X_{L0})} \bullet i_{20} \right] \\ &= 3i_{20} \left[1 - \frac{X_{L0}}{k(X_{SM0} + X_{H0} + X_{L0})} \right] \\ &= 3i_{20} \frac{k(X_{SM0} + X_{H0}) + (k-1)X_{L0}}{k(X_{SM0} + X_{H0} + X_{L0})} \end{aligned} \quad (4)$$

2.2.2 Zero Sequence Circuit of Neutral-point Grounded by Small Reactance Autotransformer. Because Y type connection of high voltage side, when grounding fault occurs at neutral point small reactance grounding autotransformer, the sum of three phase current in the positive sequence network is zero, and so does the current flows through small reactance. Installation small neutral-point reactance on autotransformer will not change the magnitude of positive sequence equivalent impedance, so it will not affect the normal operation of power system. But installing small reactance on autotransformer's neutral point will affect the zero sequence circuit because zero sequence current flows through neutral point[4].

When outside grounding fault occurs on medium voltage side of the small reactance grounded autotransformer, zero sequence equivalent circuit is similar to the circuit shown in figure 2. But considering influence of neutral point small reactance to zero sequence circuit, the zero sequence equivalent impedance changes[5-7].

When autotransformer is grounded with small reactance X_n , zero sequence impedance converted to high voltage side, medium voltage side and low voltage side are X'_{H0} , X'_{M0} , X'_{L0} .

$$\begin{cases} X'_{H0} = X_{H0} + 3X_n(1-k) \\ X'_{M0} = X_{M0} + 3X_n k(k-1) \\ X'_{L0} = X_{L0} + 3X_n k \end{cases} \quad (5)$$

For step-down transformer, the ratio k equals to U_1/U_2 , which is greater than or equal to one. When autotransformer is grounded with small reactance, the zero-sequence equivalent impedance of each side contains additional terms of neutral small reactance. Zero-sequence impedance of high-voltage side decreases, but which of medium-voltage side and low-voltage side increases.

When outside grounding fault occurs on medium voltage side of neutral-point small reactance grounded autotransformer, the zero-sequence current of neutral-point I'_{ZX} is as following.

$$\begin{aligned} I'_{10} &= kI_{10} \\ &= \frac{X_{L0} + 3X_n k}{X_{SM0} + X_{H0} + 3X_n(1-k) + X_{L0} + 3X_n k} \bullet i_{20} \\ &= \frac{X_{L0} + 3X_n k}{X_{SM0} + X_{H0} + X_{L0} + 3X_n} \\ I'_{ZX} &= 3I = 3(I_{20} - I_{10}) \\ &= 3 \left[i_{20} - \frac{X_{L0} + 3X_n k}{k(X_{SM0} + X_{H0} + X_{L0} + 3X_n)} \bullet i_{20} \right] \\ &= \\ &= 3i_{20} \frac{k(X_{SM0} + X_{H0}) + (k-1)X_{L0}}{k(X_{SM0} + X_{H0} + X_{L0} + 3X_n)} \end{aligned} \quad (6)$$

Based on the above analysis, it can be seen that when autotransformer is grounded with small reactance, due to the influence of neutral point small reactance on the zero sequence equivalent circuit, zero sequence current exists on each side of the autotransformer, and the corresponding zero sequence current is reduced by neutral-point small reactance.

3. Application and Relay Protection Setting for Neutral-point Small Reactance

3.1 Application of Neutral-point Small Reactance

When autotransformer is grounded by small reactance, the magnitude and direction of zero-sequence current at neutral point are related to the magnitude of system impedance at medium and high voltage side. In order to avoid the insufficient sensitivity of zero sequence current protection on high and medium voltage side after switching off from high or medium voltage side, zero sequence over-current protection should be set on the neutral point.

At present, Shandong power grid sets a separate protection for small reactance on autotransformer's neutral point to monitor zero sequence current. When protection setting of the neutral-point small reactance is considered, only three-step zero-sequence over-current protection is set. All other protections except the third step of zero-sequence over-current protection are deactivated, and the third step of zero-sequence over-current protection only sends signals but does not trip. Actually, the independent configuration of neutral-point small reactance protection is more to monitor neutral-point reactance, so as to avoid insufficient sensitivity of zero sequence current protection at high and medium voltage sides.

3.2 Relay Protection Setting of Neutral-point Small Reactance

Protection setting for a 500kV substation's neutral point small reactance is shown[8-9].

Relevant parameters of small reactance at neutral point are as follows: measured reactance $X_n = 5 \Omega$, rated current $I_e = 400A$, thermal stable current $10kA/2s$, $4kA/9s$.

CT ratio of each side are as follows: neutral point reactance zero sequence CT: 500/1, high voltage side CT: 3000/1, medium voltage side CT: 3200/1, common winding CT: 3200/1.

The first step of neutral-point small reactance's zero sequence over-current protection cooperates with the second step of autotransformer's high voltage side and medium voltage side zero sequence over-current protection, and the time cooperates with smaller one of this two protection. Protection setting of the second step of autotransformer's high voltage side is $0.3A/6.3s/6.6s$. Protection setting of the second step of autotransformer's medium voltage side is $0.3A/5.3s/5.6s$.

$$I_j = 1.1 \times (0.3 \times 3000) / (500/1) = 1.98A \quad (8)$$

$$I_j = 1.1 \times (0.3 \times 3200) / (500/1) = 2.112A \quad (9)$$

I_j takes 2.2A. Considering that the time should cooperate with time of 500kV transmission line's zero sequence protection, and have the same value with this substation's neutral point small reactance protection, so time takes 6.5s.

The second step of neutral-point small reactance's zero sequence over-current protection and autotransformer's common winding protection has the same value $0.15A/6.6S$.

$$I_j = 1.1 \times (0.15 \times 3200) / (500/1) = 1.056A \quad (10)$$

The second step of zero sequence over-current protection takes value of $1.1A/7S$

The third step of neutral-point small reactance's zero sequence over-current protection is setting to 1.05 times rated current considering overload.

$$I_j = 1.05 / 0.95 \times 400 / (500/1) = 0.8842A \quad (11)$$

The third step of zero sequence over-current protection takes value of $0.9A/9S$.

Finally, the three-step zero-sequence over-current protection satisfies the requirements of thermal stability.

4. Effect of Limiting Short Circuit Current by Installing Small Reactance on Neutral Point

In this paper, a 500kV autotransformer model is established using UMEC transformer model in PSCAD/EMTDC. The effect of limiting short-circuit current by installing small reactance at neutral point is simulated and analyzed.

The parameters of 500 kV autotransformer are as follows: rated capacity 1000MW; rated voltage of three sides 525 kV/230 kV/35 kV; no-load loss 204.4 kW; no-load current 0.039%; high-middle voltage side impedance 19.59% (the percentage of voltage drop on impedance when autotransformer passes through rated current). Figure 3 shows the model of single-phase neutral point directly-grounded autotransformer[10].

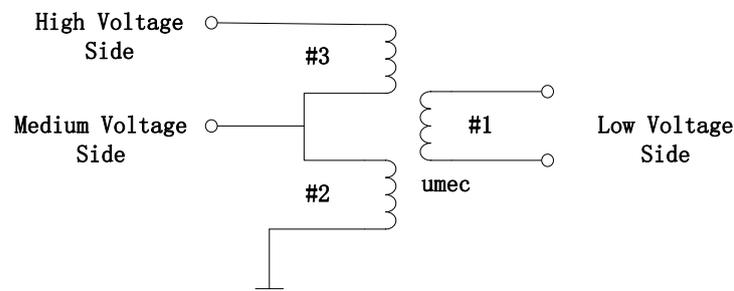


Figure 3. The model of single-phase neutral point directly-grounded autotransformer

In order to study the influence of installing neutral reactance on the 220kV busbar's short-circuit current in 500 kV substation when single-phase grounding fault occurs, the external equivalent impedance of high-voltage side, medium-voltage side and low-voltage side is calculated by protection setting software. Figure 4 shows the PSCAD/EMTDC simulation model of a 500kV substation.

Single-phase fault occurs on medium-voltage side of autotransformer[11-14]. The difference of short-circuit current before and after installing small reactance are compared.

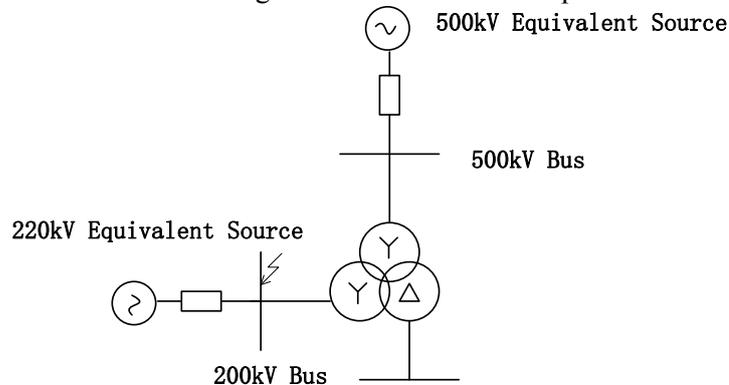


Figure 4. Simulation model of a 500kV substation

When single-phase grounding fault occurs in 500 kV substation's 220kV bus, the waveform of short-circuit current is shown in figure 5.

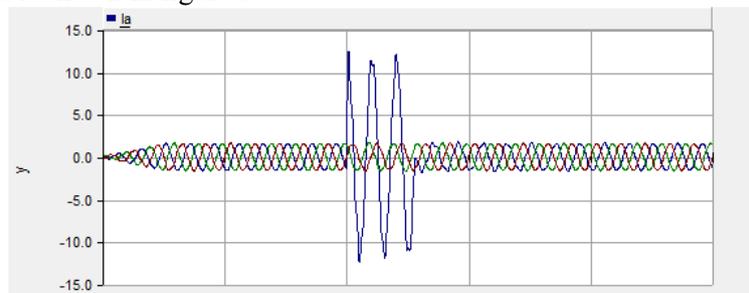


Figure 5. Short-circuit current waveform of single-phase grounding fault

The single-phase short-circuit fault current of 220kV bus is compared when 5-20 Ω small reactance is installed on the neutral point of autotransformer. Table 1 shows the single-phase short-circuit fault current when different value of small reactance is installed on autotransformer.

Table 1. Single-phase short-circuit fault current

Value of mall reactance	Short-circuit current
0 Ω	32.8kA
5 Ω	31.6kA
10 Ω	30.8kA
15 Ω	29.9kA

But when 5-20 Ω small reactance is installed on the neutral point of autotransformer, the three-phase short-circuit fault current of 220 kV bus maintains about 26 kA without obvious change. When single-phase fault occurs on 500kV bus, there is not obvious change on short current with different small neutral point grounding reactance.

5. Conclusion

Currently, single-phase short circuit current exceeds three-phase short circuit current in some of Shandong 500kV substation's 220kV bus. This will threaten the safety operation and system reliability of power grid. So mall neutral-point reactance is installed in some 500kV substations to limit single-phase short circuit. Meanwhile, in order to limit short-circuit current further, bus runs separately in some substations.

- (1) Installing small neutral-point reactance on 500kV autotransformer can limit single-phase short current effectively. But there are no obvious effects on three-phase fault and two-phase fault, and so as to the high voltage side.
- (2) Installing small reactance on autotransformer's neutral point will pose influence to zero sequence circuit, so protection setting for autotransformer should be reconsidered. At present, Shandong power grid installs a separate protection for small reactance on autotransformer's neutral point to monitor zero sequence current.
- (3) For some substation with serious short-circuit current over standards, delimiting and districting operation, bus separate running can be used to limit fault current.

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