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Study on closed loop operation of low voltage distribution network under three-phase unbalanced condition

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Abstract. The closed loop operation to achieve power load can greatly improve the power supply reliability of low-voltage distribution network, but because of the low voltage distribution network asymmetry and the difference of voltage loop, closed loop operation will not change the balance of system, generating loop impulse current, affect the safe operation of power grid. So this paper considers the low voltage distribution network closed loop current in the load transfer method, and through the simulation and analysis of the distribution network load rate and the unbalance of the loop current and loop distribution after unbalance effect, verify the closed loop operation of distribution network considering the unbalanced degree of necessity.

1. Introduction

Low voltage power distribution network, as the end of the power grid, takes the important responsibility of providing safe and reliable electricity to the end users [1]. Due to the load types tending to diversification, it is more common that the low voltage distribution network works asymmetrically because of asymmetric line parameters, asymmetric three-phase load operation, access of single phase load [2].

At the same time, the user has higher requirement for power supply service quality. In order to improve the reliability of power supply, at present, China’s power grid construction type adopts the model of "construction with closed loop and operation with open loop " [3]. The grid structure can not only improve the efficiency of the power configuration, but also down load without power cut which ensures power supply to the users by the closed loop operation when it is in fault, maintenance, engineering reform and load transfer. Comparing to exchange distribution equipment in short time, expanding the conductor cross section, increasing variable volume and other methods which can improve the reliability of power supply have the advantages of shorter time, less spend and high efficiency [4].

However, when making closed loop operation without power cut, because of the presence of voltage amplitude and phase angle difference on both ends of the closed loop, impulse current and steady-state current after through switch will produce impact on the grid at the moment when the loop is closing. So we need to check whether steady-state current can meet the requirements of equipment when operating closed loop. In the literature [5], the closed loop steady-state current is equivalent to the superposition between the open loop steady-state current and the equivalent current caused by the voltage difference on both sides of the loopback point. The method does not take into account the load transfer caused by the loop operation, and the result compared to actual closed loop current has deviation; Literature [6] proposed the closed loop current affected by the closed loop feeder load distribution, and set up three kinds of typical load model, increasing, decreasing, uniform distribution and calculated the closed loop current to verify the load distribution has impact on closed loop current. But it did not put forward how to apply this method to the actual; in combination with the actual situation, literature [7] researched the impact that the voltage of closed loop point had on the closed loop current, and summed up the closed loop conditions and determination methods. But it did not give the calculation method of closed loop point voltage difference.

At present, the criterions in view of closed loop current calculation and closed operation are most based on the study of medium voltage distribution network closed loop. The calculation of closed loop current are most based on the situation that the source voltage, the line impedance and the loads do not change before the loop closes. Besides, it does not consider the actual situation that the 380 voltage three-phase four-wire and low voltage distribution system works asymmetrically. The tide will redistribute while the network is making the loop closed. And it maybe cause the current in some lines over the limitation and the transformer imbalanced degree is more than allowance.

For this defect, this paper proposed a method which could be applied to the practical situation, taking into account the load transformation, the calculation of simple closed loop current and closed loop point’s voltage difference. Considering the asymmetry of low voltage distribution network running status and the national requirements of imbalanced degree, it also proposed the judgment basis of low voltage distribution network closing operation and verified the accuracy of the closed loop current’s calculation by simulation. Otherwise, it analyzed the impact that the low voltage distribution transformer’s load rate and the imbalanced degree had on the closed loop current and the imbalanced degree of distribution network after closing loop.

2. The calculation of closed loop

2.1. Closed loop steady-state current

In low voltage distribution network, in order to meet the different electrical requirements of single-phase or three-phase loads, the distribution transformers are neutral-point solid ground system [8], so we can calculate in single phase when calculating the closed loop current.

Due to wide distribution of low voltage distribution network, a single distribution transformer capacity is limited, short transmission distance, small load, small power loss, if we model and calculate according to the actual load distribution, it will be heavy work, time consuming and cannot be promoted in the practical application [9]. So it adopted the double end power network model to simplify the equivalent. Figure 1 is the typical closed loop grid of low voltage distribution network. Respectively, S_{T1} , S_{T2} , $S_{T1}^{'}$, $S_{T2}^{'}$ are two closed loop distribution transformers’ output power in low voltage side. $\dot{U}_H$ is the bus voltage of the distribution transformer in high voltage side(If the closed loop grid does not belong to the same superior feeder, closed loop switch voltage difference on both ends is affected by the superior power grid operation state. Because the voltage difference and the risk of closing loop are huge, at present, there is the same superior feeder’s low voltage distribution network closing loop when in the same area), S_1 , S_2 are load power of the distribution transformer’s main line, L_1 , L_2 are load power of the unclosed loop distribution transformer’s line, Z_{T1} , Z_{T2} are the two distribution transformers’ resistance, U_{2N} is the distribution transformer’s rated voltage in low voltage side, $\Delta\dot{U}$ is the both ends voltage difference in the closed loop point, k is the distribution transformer ratio.

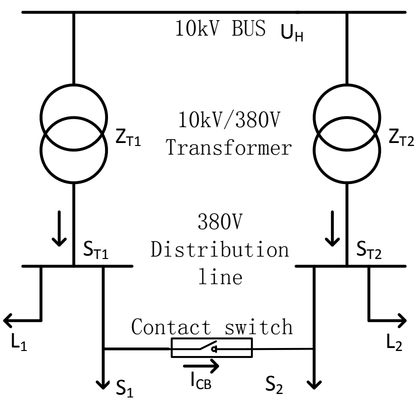

Figure 1. Typical closed loop networks

Before closing loop, the network power meet
$S_{T1} = S_1 + L_1$, $S_{T2} = S_2 + L_2$

We calculate closed loop line's steady-state current I_{CB} by using the way closed network power flow calculation. Now we assume the contact switch's power is S_{CB} after closing loop, the line's resistance and the distribution transformer's voltage in high voltage side are not change. Then

$$S_{CB} = \frac{(S_2 + L_2)\bar{Z}_{T2} - (S_1 + L_1)\bar{Z}_{T1}}{\bar{Z}_{T1} + \bar{Z}_{T2}} + \frac{\Delta\bar{U} * U_L}{\bar{Z}_{T1} + \bar{Z}_{T2}} \quad (1)$$

$$S'_{T1} = S_1 + L_1 - S_{CB} \quad (2)$$

$$S'_{T2} = S_2 + L_2 + S_{CB} \quad (3)$$

So the closed loop steady-state current is

$$I_{CB} = \bar{S}_{CB} / \bar{U}_L = \frac{(S_2 + L_2)\bar{Z}_{T2} - (S_1 + L_1)\bar{Z}_{T1}}{(\bar{Z}_{T1} + \bar{Z}_{T2})\bar{U}_L} + \frac{\Delta\bar{U}}{\bar{Z}_{T1} + \bar{Z}_{T2}} \quad (4)$$

Choosing the maximum of closed loop steady-state current is I_m . We can see that the magnitude of the steady-state current value of the closed loop is mainly affected by the network current distribution, the distribution transformer's impedance, the closed loop point voltage difference from formula (4).With the difference of closed loop point's voltage, distribution transformer's load and distribution transformer's impendence increasing, the closed loop steady-state current will increase and it will decrease with distribution transformer's impendence increasing.

2.2. The difference of the closed loop point's voltage

In the case of grid parameters and load determination, the key to obtaining circulation is to find the voltage difference. The losses calculated by converting distribution transformer's resistance in low voltage side into it in high voltage side are ΔU_{T1} , ΔU_{T2} .Then

$$\Delta\dot{U}_{T1} = \frac{P'_{T1} R_{T1} + Q'_{T1} X_{T1}}{U_H} + \frac{P'_{T1} X_{T1} - Q'_{T1} R_{T1}}{U_H} \quad (5)$$

$$\Delta\dot{U}_{T2} = \frac{P'_{T2} R_{T2} + Q'_{T2} X_{T2}}{U_H} + \frac{P'_{T2} X_{T2} + Q'_{T2} R_{T2}}{U_H} \tag{6}$$

The voltage of distribution transformer in low voltage are U_{L1}, U_{L2} .Then

$$\begin{aligned} \dot{U}_{L1} &= \frac{\dot{U}_H - \Delta\dot{U}_{T1}}{k} \\ \dot{U}_{L2} &= \frac{\dot{U}_H - \Delta\dot{U}_{T2}}{k} \end{aligned} \tag{7}$$

The difference of closed loop's voltage is $\Delta\dot{U} = \dot{U}_{L1} - \dot{U}_{L2}$.

2.3. The closed loop impact current

Under normal circumstances, closed loop contact switch is normally open state. The distribution transformers independently supply their respective loads. When distribution transformer does not work or need repaired, it will need switching operation by closing contact switch and at the moment it will produce impact current [10].The maximum instantaneous value i_M and the maximum effective value I_M of closed loop can be calculated by using the calculation formula of short-circuit impulse current. They are

$$i_M = (1 + e^{-0.01/T_a}) I_m = k_M I_m \tag{8}$$

$$I_M = \sqrt{I_{CB}^2 + \left[(k_M - 1)\sqrt{2} I_{CB}\right]^2} = \sqrt{1 + (k_M - 1)^2} I_{CB} \tag{9}$$

In the two formulas, k_M is impact coefficient, T_a is decay time constant, and $T_a = \frac{L_{T1} + L_{T2}}{R_{T1} + R_{T2}}$.

3. Simulation Study

This paper chooses a two 380V low voltage distribution network in Yuhang area of Hangzhou city to simulate and analyze, In the example, the distribution transformer on both sides of the loop is the same type. Its capacity is 400kVA. the connection mode is Dyn11. the impedance voltage is 4%.

When the two distribution transformers' three-phase load are balanced, the load rate in distribution transformer 1 is constant, but it in distribution transformer 2 varies from 0 to 100%. Its closed loop current calculation value changes as shown in Figure 2 solid line, the closed loop current simulation value changes as shown in Figure 2 dotted line. The figure on the right shows the transformer 1 load rate. Due to ignore line impendence when calculating, there is certain error between the calculation value and the simulation value, but the error can be accepted. It verifies the accuracy of the loop current calculation method. We can know when the two models with the same type closing, the closed loop current will increase with the two transformers' load rate increasing and the closed loop current is minimum when the two distribution transformer rate is the same.

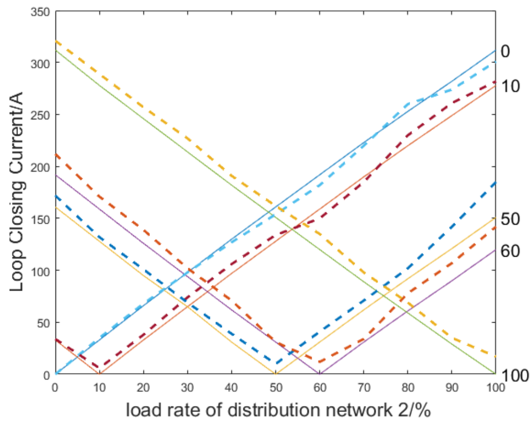

Figure 2 Relationship between loop current and load rate of distribution transformer

When the two distribution transformers' loads are imbalanced, we assume the transformer 1 load's imbalanced degree is constant and A, B, C three-phase load rate from large to small is arranged as A> B> C; The transformer 2 load's imbalanced degree varies from 0 to 15% and A, B, C three-phase load rate from large to small is also arranged as A> B> C. When the total load rates of the transformer 1 and 2 remain unchanged and are 30%, The maximum change in the closed loop current in the three phases is shown in the solid line in Fig3. The distribution network's imbalance degree after closing loop is shown in the solid line in Fig4; When the total load rates of the transformer 1 and 2 remain unchanged and the total load rates are respectively 30% and 90%, The maximum change in the closed loop current in the three phases is shown in the dotted line in Fig3. The distribution network's imbalance degree after closing loop is shown in the dotted line in Fig4.

We can know that the distribution transformer's imbalanced degree has slight impact on closed loop current by analyzing the curve in Fig3 and the closed loop current affected mainly by the closed loop load rate difference; The smaller the load rate difference in the closed loop , the smaller the variation range of the closed loop maximum current with the load imbalance. When the closed loop distribution transformer has the same load rate and the same direction of imbalance, the difference of imbalanced degree and the closed loop maximum current will be smaller.

We can know that closing loop operation will change the distribution network's imbalanced degree by analyzing the solid line in Fig4. When the two distribution transformers have the same load rate and load's imbalanced degree, the imbalanced degree of the distribution network after closing loop is changed relative to that before the loop, its imbalanced degree is affected by the two distribution networks' imbalanced degree before closing loop and bigger than the average of the two distribution networks' imbalanced degree; We can know that the network's imbalanced degree after closing loop is mainly affected by the higher load's imbalanced degree before closing loop when the two closed loop distribution transformers' load rates are different and the difference is large by analyzing the dotted line in Fig4. When the distribution transformers' imbalanced degree is 15% (The distribution transformer allows the maximum degree of imbalance) before closing loop, the distribution network's imbalanced degree is more than 15% after closing loop. So it is necessary to consider load shift caused by closing loop operation and calculate weather network's imbalanced degree can meet the requirement in the closed loop operation judgment condition.

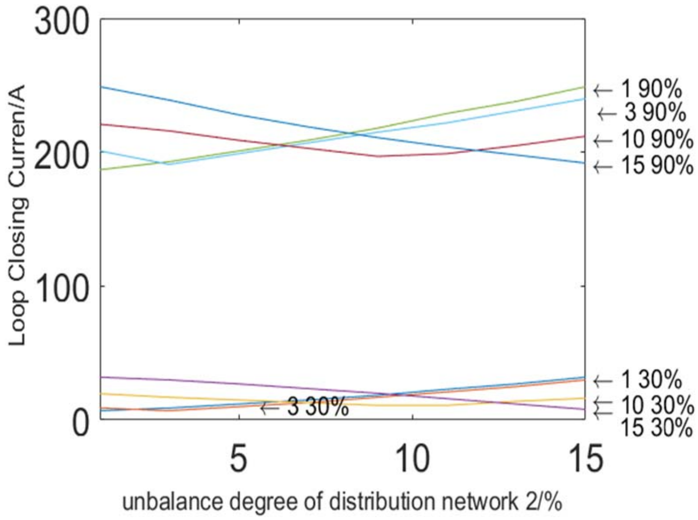

Figure 3 Relationship between current and unbalance of distribution transformer loop

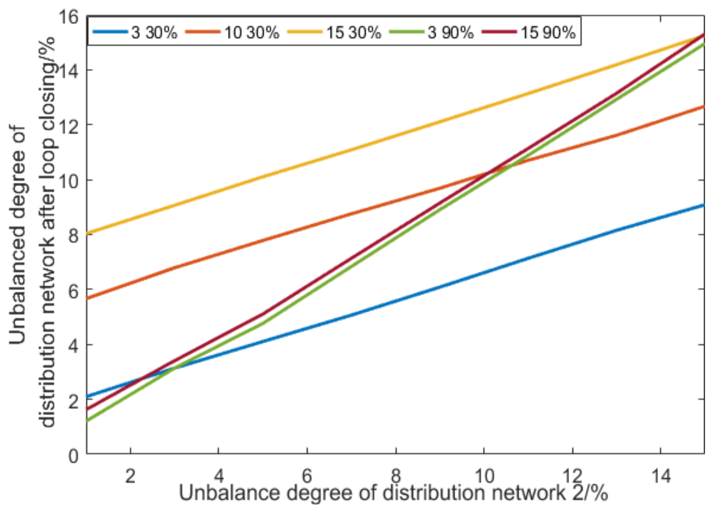

Figure. 4 unbalance degree of distribution network after loop closing

4. Conclusion

This paper mentioned the closed loop simplified calculation method in low voltage distribution network with considering load shift situation which improved the closed loop current calculation's accuracy. And for three-phase asymmetrical operation of low-voltage distribution network, it analyzed the impact that closing loop operation had on distribution network's imbalanced degree, improving the operation judgement conditions and safety. In the end, this paper verified the calculation method's accuracy and the correctness of theoretical analysis by simulation.

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