THE FAULT LOCATION TECHNOLOGY USING TRANSIENT SIGNALS FOR SINGLE PHASE EARTH FAULT IN NON-SOLIDLY EARTHED NETWORK

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ABSTRACT

Earth fault accounts for about 80% of the distribution network faults, which makes the detecting and locating of single phase earth fault more important. This paper analyzes the transient process of single phase earth fault and the distribution characters of transient signal in system, and then proposes a new locating method with the comprehensive utilization of transient fault information. This method has the characteristics of both high reliability of transient reactive power direction method and wide adaptability of transient current similarity and transient current polarity comparison methods. Simulation test and field test verified the effectiveness of this technology.

INTRODUCTION

With the society relying more on power, financial losses and harmful effects caused by power failure (especially the unexpected failure outage) become more and more serious. Studies have shown that[1] when reducing 1 kWh power supply caused by power outage, the average loss of users will be over 40 yuan. It can be calculated that the financial loss of China can reach hundreds billion yuan because of power outage.

The single phase earth fault of isolated neutral or via Petersen coil grounded distribution networks is difficult to detect since the fault is unstable and the fault current is too small[2]. However, according to statistics, earth fault accounts for 80% of all distribution network faults, which makes the locating technology of single phase earth fault more and more important.

In recent years, line detection technology based on transient information of single phase earth fault has already been used in the field successfully[3-4], whose success rate reaches 95% (others are because of the low success rate of high resistance grounded faults test), which lays a good foundation for fault locating based on transient information.

On the basis of analyzing transient distribution characteristics of single phase earth fault, this paper proposes a new fault locating method of single phase earth fault which combines the direction of transient power, the similarity and polarity of transient current. This technology has been verified by simulation test and field test.

SINGLE PHASE EARTH FAULT TRANSIENT DISTRIBUTION CHARACTERISTICS

Transient process of earth fault

Transient process of single phase earth fault is caused by the resonance between equivalent inductances and capacitors. Transient characteristics on two sides of fault point should be studied intensively as far as fault locating is concerned. For convenience, the equivalent circuit for analyzing main resonance frequency transient characteristics can be seen as Fig1 approximately.

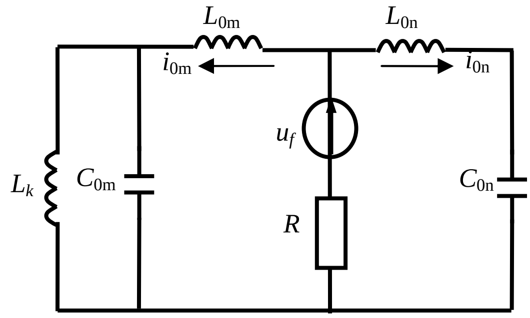

Fig.1 Equivalent circuit of single-phase earth fault for fault locating

Fig. 1 shows the traditional circuit of single-phase earth fault presented in [5-6]. Where, L_0, C_0 are the inductance, capacitance of zero modulus, respectively. R_0 is the sum of zero-mode equivalent resistance and three times of fault resistance. u_f is virtual power of fault point.

As is shown in Fig1: u_f is zero modal (zero sequence, the same below) voltage of fault point and is equal to reverse voltage of fault phase before fault; R is total resistance of fault currents flow past; L_{0m} and C_{0m} are zero modal inductance and capacitor on the upper line (the side of bus) of fault point while L_{0m} and C_{0m} are zero modal inductance and capacitor on the downstream(the side of

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load) of fault line; L_k is Peterson coil's equivalent inductance; i_{om} and i_{on} are transient zero modal current on the upper line and downstream of fault point.

According to Fig1, we can consider the transient processes on two sides of the fault point are independent. That is to say, transient process of upstream is produced by line between fault point to bus , all sound lines and Petersen coil, while downstream transient process only produced by fault point to the end of the line.

As a inductance paralleled with zero modal capacitor of upper line of the fault point, Petersen coil only has certain effects on resonance frequency and amplitude in high resistance grounded faults, whose compensating effect of fault current decreases with the increase of frequency. Similar to fault line detection, Petersen coil can be neglected when analyze the distribution of transient current in system and locating technology.

The majority of faults are unstable arc or intermittent grounding, which makes power frequency unstable and transient signals occur frequently. Fig2 shows an earth fault current signal recorded in the field.

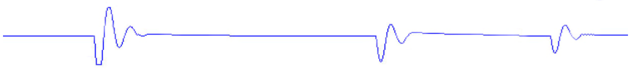

Fig.2 A typical current wave of unstable earth fault

Distribution of transient fault current in system

Usually, there are several outgoing lines in distribution system, the line on upper line of fault point is much longer than downstream, so the relevant inductance and distributed capacitor are also much greater than those of downstream. Therefore, resonant frequency of transient process on upper line of fault point is low while the one on downstream is high. Differences existed between them and they have a low degree of similarity.

For monitoring points on sound lines and downstream line of the fault point, their fault currents are the currents of distributed capacitance on downstream line of fault point, with small amplitude and a flow direction from bus to line. And the flow direction of transient power is also from bus to line. For monitoring points between fault point and bus, the fault current is the distributed capacitance current of both all sound lines and upstream line of fault point, whose amplitude is large and flow direction is from line to bus, so does the transient power. The transient fault current polarity on both sides of fault point is opposite.

For two monitoring points on upstream or downstream of fault point (besides the fault point), the differences of their transient currents are caused by the distributed capacitances between them, which change little, so their transient current amplitudes are approximately the same and their similarity is high. Fig3 shows the distribution of earth fault transient zero modal current in system.

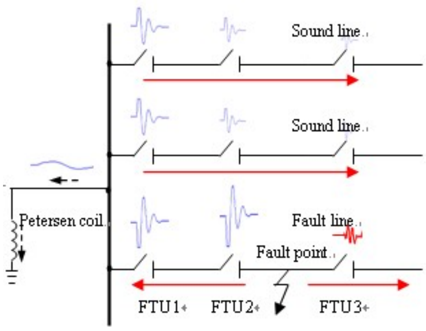

Fig.3. Transient current distribution of single-phase earth fault

LOCATING METHODS BASED ON TRANSIENT CURRENTS

Transient power direction, transient current similarity and transient current polarity all can achieve fault locating of single phase earth fault, but their technical features are different and comprehensive utilization of their information can improve the reliability and adaptability of fault locating.

Locating method based on transient power direction

Locating criterion

The transient (reactive) power on upstream line of fault point flows to bus and downstream line flows to the contrary direction, which can be used to determine fault section.

On the basis of capacitive constraints between transient zero sequence voltage (or specific line voltage corresponding with fault phase) and zero sequence current on Special Frequency Band(SFB)[5-6], we can define transient reactive power (Q) as the average power of the reverse polarity of the Hilbert transformation of voltage ($U(t)$) in SFB and current ($i_0(t)$):

$$Q = -\frac{1}{\pi T}\int_0^T i_0(t)\int_{-\infty}^{\infty}\frac{u(\tau)}{t-\tau}d\tau dt$$

In the formula: T is transient signal duration.

Or define transient reactive power (Q) as the average power of the derivative of ($U(t)$) in SFB and current ($i_0(t)$):

$$Q = \frac{1}{T}\int_0^T i_0(t)du(t)$$

When $Q<0$, the transient reactive power flows to bus , otherwise it flows to line when $Q>0$.

The criterion of fault section locating is: Flow directions of transient reactive power on two sides of fault section are reverse, namely, Q on two sides of fault section are contrary.

Analysis of feature and adaptability

For unstable earth fault, every fault direction (direction of reactive power) of transient process is unchangeable. Namely, this method won't be influenced by unstable arc or intermittent grounding and also doesn't need the FTU with precisely time setting. The method has high detecting reliability.

FTU only needs to report the fault direction to master station, which makes the amount of data transmission smaller and pressure of communication lower. Master station locating algorithm is simple (like fault location algorithm of double power short trouble). It is convenient for the cooperation of different manufacturer goods.

It needs zero sequence voltage or specific line voltage signal correspond with fault phase (for example, earth fault of phase A needs line voltage of BA or CA) to calculate transient power. This method can only be applied to switching station and substation, or monitoring points that install PT of specific phase fault .

Locating method based on transient current similarity

Locating criterion

The feature used to locate fault section is that the similarity of transient zero sequence current is low on two sides of fault section while the similarity on two sides of sound section is high.

FTU can not synchronous recording transient current signal precisely in engineer. When calculating the similarity factor($\rho_{k,k+1}$) of transient zero sequence current ($i_{0,k}(t)$ and $i_{0,k+1}(t)$) on two adjacent monitoring points, it needs a moderate excursion of one signal to get a set of similarity factors and take the maximum absolute value as the similarity factor[7], that is :

$$\rho_{k,k+1} = \underset{\tau\in[-\mathrm{T_t},\mathrm{T_t}]}{Max}\left(\left|\rho_{k,k+1}(\tau)\right|\right)$$

$$= \underset{\tau\in[-\mathrm{T_t},\mathrm{T_t}]}{Max} \frac{\left|\int_0^T i_{0,k}(t) i_{0,k+1}(t+\tau)dt\right|}{\sqrt{\int_0^T i_{0,k}^2(t)dt \int_0^T i_{0,k+1}^2(t)dt}}$$

In the formula: T_t is the max synchronous error among FTU; Current data that over the measurement range [0,T] can be replenished by zero. Similarity factor should be:

$$0 \le \rho_{k,k+1} \le 1$$

Fault section can be determined by comparing the transient zero sequence currents of two adjacent FTU on each section of fault line. Considering that there is only one adjacent FTU existed at the end of the line and FTU may be not actuate for small transient current on downstream of fault point, fault section criterions are:

(1)The section is fault section when the similarity factor of two sides transient current is minimum and less than set value.

(2)In all the sections that FTU reports the fault transient current, their similarity factors are all greater than set value, fault section is the downstream of last FTU.

The value of similarity factor is an empirical value that can be set between 0.5 and 0.8.

Analysis of feature and adaptability

It is independent of zero sequence or line voltage, only needs zero sequence current signal, and is adapt to all monitoring points.

For unstable earth fault, if transient process occurs over twice in a short time (within 10ms) and they are different from each other, the calculating of transient current similarity would be influenced.

All FTUs need to upload fault recording data to master station that makes the amount of data transmission large and pressure of communication heavy. Master station locating algorithm is complicated and there is certain difficulty for cooperation of different manufacturers' goods.

Computer simulation shows that the method based on transient current similarity can achieve fault locating precisely in majority cases of single phase earth fault, however, transient current similarity factor on two sides of fault point may be bigger in minority cases, which makes locating failure. And now location algorithm based on other theory should be used to achieve fault locating.

Locating method based on transient current polarity comparison

Use the characteristic that the polarity of the transient zero sequence currents on two sides of fault section is contrary to determine fault section.

P_{km} is defined as the polarity factor of two currents signal so the polarity relation of two adjacent monitoring points' transient zero sequence current i_{0n} and i_{0m} is:

$$P_{km} = \frac{1}{T}\int_0^T i_{0n}(t) i_{0m}(t)dt$$

In the formula: T is transient signal duration.

When P_{km} >0, it indicates i_{0n} and i_{0m} are the same polarit and the polarity is contrary when P_{km} <0.

Criterion of determine fault section is: compare the polarity of adjacent monitoring points' transient zero sequence currents, if the polarity are contrary, fault section locates between the two points; if all the polarities are the same, fault section locates between the last monitoring point and end of line.

This method only needs zero sequence current signal, and is independent of zero sequence voltage or line voltage, however, it requires the TA is installed in correct polarity . Locating results would be influenced when TA polarity is installed reversely.

Locating method based on transient current approximate entropy

Condense transient current signal into a entropy that reflects the complexity of current waveform by using approximate entropy algorithm and fault section is determined by the comparison of adjacent FTU current entropy value by master station[8].

This method is also on the basis of transient current similarity theory. Advantages are: FTU doesn't need to report recording data to master station, reducing the pressure of communication; master station won't calculate similarity factor and the algorithm is relatively simple. But because the relation between signal entropy and signal complexity is nonlinear and there exist non-uniqueness, the actual effect remains to be further verified.

LOCATING METHOD COMPREHENSIVE UTILIZATION OF TRANSIENT INFORMATION

Transient power direction method is more reliable than transient current similarity and transient current polarity comparison method, but the former only apply to part of monitoring points and the latter two are suitable for all monitoring points. Take it into consideration that misjudgment would occur in minority when transient current method is used alone, we can determine fault section according to voltage signal acquired by FTU on fault line by a comprehensive utilization of transient power direction, transient current similarity and transient current polarity comparison method:

(1)Use fault direction information of FTU that has conditions of calculating transient power direction to determine a large fault section(may include one or more FTU that have no condition of calculating transient power direction)

(2)In the large section, use transient current similarity and polarity relationship to determine specific fault section: when the similarity factor of transient currents is large and currents are in a same polarity, the section is sound section, otherwise it's fault section.

On the fault line showed in Fig3, suppose FTU1 can acquire zero sequence voltage signal, we can calculate transient power direction of any earth phase; similarly, suppose FTU3 can get CA line voltage, we can calculate transient power direction of phase A or B, no voltage signal can be obtained by FTU2.

For earth fault of phase A or B, large fault section can be determined by transient power direction of both FTU1 and FTU3. If fault is located between FTU1 and FTU3, the specific fault section can be detected by transient current similarity and polarity relationship between FTU1 and FTU2.

For earth fault of phase B, fault locating can be realized only by transient current similarity relationship of the three FTU .

The locating method that comprehensive utilization of transient fault information has been tested in the field.The field test verified the effectiveness of this technology.

CONCLUSIONS

Single phase earth fault locating has an important effect on reducing power-cut time and can improve power distribution reliability.

After determining the fault line by fault line detection device, firstly determine the large fault section by fault direction information of FTU that possess the ability of calculating transient power direction in fault line. Then, locate specific section by transient current similarity and polarity relationship among FTU in large section. This kind of locating method synthesizes advantages of transient power direction , transient current similarity, and transient current polarity which possess high reliability and wide adaptive range. Simulation test and field test verified the effectiveness of this technology.

The fault locating method with comprehensive utilization of transient fault information has no use for additional earth resistance or signal injection device, which makes it a small investment that will be not only free of Petersen coil influence, detecting reliability but also be easily achieved.

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