A NEW PRINCIPLE BASED ON PEARSON CORRELATION COEFFICIENT TO AVOID MAL-OPERATION OF THE RESTRICTED EARTH FAULT PROTECTION

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ABSTRACT

This paper presents a new principle based on the Pearson correlation coefficient principle to avoid mal-operation of the restricted earth fault protection (REF), by calculating the correlation coefficient of 3I0 (residual current) and I_N (star-point current) to determine internal or external fault.
When the transformer earth fault occurs, the direction and intensity of 3I0 (residual current) between I_N (star-point current) almost change in the same way, that means perfect positive correlation. When the external earth fault occurs, 3I0 and IN are close to be perfect negative correlation. When CT saturation or inrush condition happens, the correlation coefficient is also significantly negative. Therefore, it can make use of the correlation coefficient calculation, in case 3I0 and I_N are strong negative correlation then restraint or delay the REF protection trip. In this way can improve the reliability of the REF protection, while avoiding the harmonic restraint principle leads to the REF protection's sensitivity reduction.
The Matlab software was used to analyse fault data which recorded from RTDS test environment obtained typical power transformer fault simulation. The test item includes: internal and external metal fault, internal and external fault occurs with CT saturation, transformer winding to ground fault and the high resistance ground fault, through theoretical analysis and dynamic simulation experiment verifies the feasibility and validity of the new principle. This new method also can easily to apply on modern digital protection device.

INTRODUCTION

Large power transformers typically use the longitudinal differential protection scheme as the main protection. However this scheme exists sensitivity problems in the condition of winding ground fault or high resistance earth fault, this weakness can use the restricted earth fault protection (REF) as an efficient supplement.
The REF protection usually protects the star winding of transformer where the neutral point is earthed. It's tripping time very short and much more sensitive than other protect functions. Modern numerical protect relay device support low impedance REF protection as shown in Figure 1. But this scheme has a problem: It requires the use of three-phase current summation (residual current), so in the event of external asymmetric fault, current transformers (CTs) saturation or inrush current can cause mal-operate. There exists slight difference between the 3 phases CTs transfer characteristic, so unequal CT currents can produce residual error current during external phase faults. No transformer neutral current is produced and sensitive relays could operate unnecessarily [1].

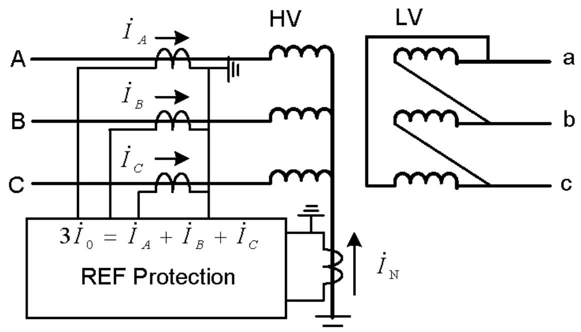

Fig. 1 Typical connection of the REF

In practical applications, there are various methods to avoid the REF to mal-operate. Paper [2] compared the REF algorithms of five different numerical relays and listed several schemes, such as change the value of restraint current in switching or after fault had been cleared, operates on vector direction of star point and residual current and so on.
There are still some other studies on this area and proposed various methods: Using the effective valve of residual current (*3I0*) and neutral current (I_N) to block the REF [3]. Choose phase to phase current instead of zero-sequence current as the restraint component [4]. Compare the direction of residual current (*3I0*) and neutral current (I_N) to prevent mistake tripping [5], etc.
In this paper, a new method based on Pearson correlation coefficient to avoid mal-operation of the REF is proposed. This method first calculate the correlation coefficient of residual current (*3I0*) and neutral current (I_N) by using sample point data in every one cycle, then depend on the correlation coefficient to determine allow to trip, delay the tripping or block the REF.

PEARSON CORRELATION COEFFICIENT

The correlation coefficient between two variables is used to reflect the linear relationship between intensity and direction, the most commonly used is the Pearson product-moment correlation coefficient, which was defined as two divided by two variable covariance standard deviation (the square root of the variance). The range of the correlation coefficient is [-1, +1], the correlation coefficient for the "+1" represents that two groups of variables are perfect positive correlation, as "-1" on behalf of two groups of variables perfect negative correlation. The formula of Pearson product-moment correlation coefficient is as following:

$$Corr = \frac{\sum_{i=1}^{N}(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{N}(X_i - \overline{X})^2}\sqrt{\sum_{i=1}^{N}(Y_i - \overline{Y})^2}}$$

Where *N* is the total number of statistic samples, in relay analysis we can use one cycle samples. For instance 24 point sample data in every cycle, here *N* equals 24. The *Corr* is reflect correlation between X and Y, use *3I0* as X and I_N as Y, then though every point sample data of this cycle, it can be calculated by the CPU of the numerical relay device.

DATA ANALYSIS OF REF MOL-OPERATE

CT saturation case 1

Figure 2 shows one mal-operated event of REF in a real substation. There was an external fault happened and lightly CTs saturation at phase A of LV side occurred, so the zero sequence current (*3I0*) of LV side can't be balanced against the neutral current of LV side. Finally the REF protection operated.

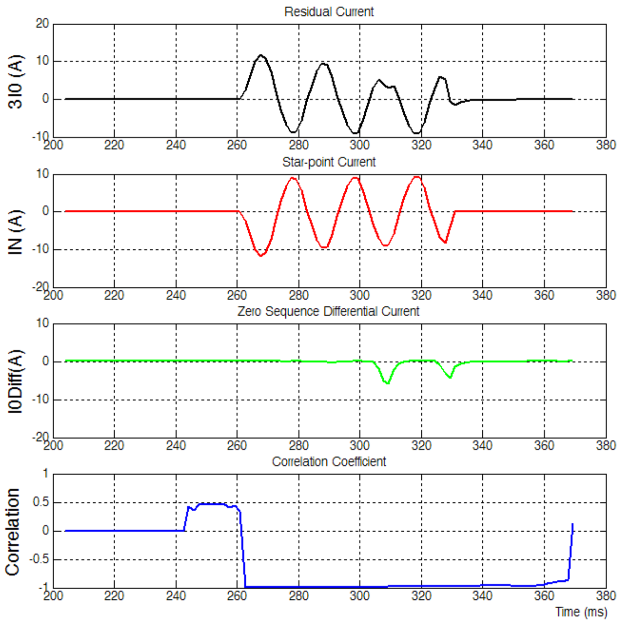

Fig. 2 External fault with CT saturation (Case 1)

First line (3I0) of the wave is calculated from 3 phase of saturated CTs, it can be clearly found that the current had been error transformed at the third cycle. Second line (IN) is the star-point current and was transformed correctly. Third line (I0Diff) is differential current of zero sequence and it was far over the setting of REF. The last line is correlation coefficient of *3I0* and I_N through the Matlab. During all of the fault process the coefficient almost equal -1， even at the moment of the CTs saturation happened. That means if use the correlation coefficient to judge this fault it must an external fault and will block the REF to avoid mal-operation.

CT saturation case 2

Figure 3 present another REF unwanted operation event. Use the Matlab software analysis fault data at the same way with case 1. From the waveform it can be found that this time the CTs saturated much heavy and caused much bigger zero-sequence differential current. It's too hard to use normal block criterion for avoiding REF mal-operation. But the correlation coefficient of *3I0* and I_N shows that this fault was also an external fault because of it always less than -0.5. It's significant different with the longitudinal differential protection that the REF is no need to been blocked by the 2nd or 3rd harmonic component to block, so like case 2 condition, it's very hard to use normal CT saturation judgement to avoid mal-operation. Again, case 2 proved that use correlation coefficient of *3I0* and I_N can significantly detect internal or external fault to block or delay the REF action.

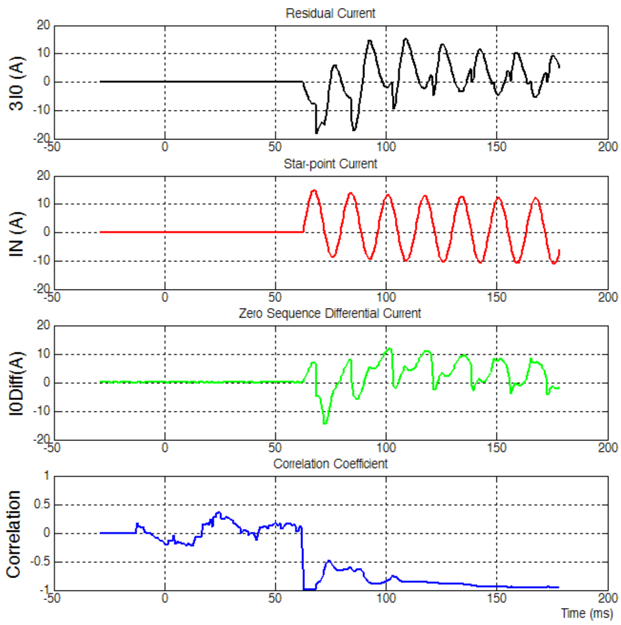

Fig. 3 External fault with CT saturation (Case 2)

DATA ANALYSIS OF REF CORRECT TRIP

Winding ground fault with residence

Sometimes transformer will happen winding to gruand fault and if the fault point is very near the star-gruand point or with resistance, only REF protection can operate.

Like 10% turns earth fault with 10Ω resistance, the longitudinal differential current will be too small than pickup setting. Figure 4 is the result of data analysis in this condition.

During the fault we can see that the *3I0* is small only 0.5A almostly, but it's changing tend the same way with the star-point current. So the correlation coefficient of them is always equal +1， means they are very positive correlated. It's very different from the result of external fault mentioned at case 1 and case 2. Hence, from the correlation coefficient it can easily find out this is an internal fault and should not block the REF protection.

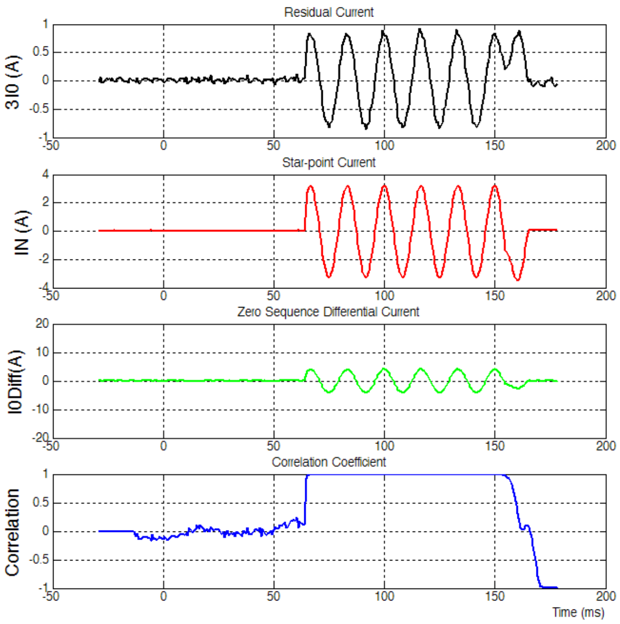

Fig. 4 Internal fault of 10% winding Phase A ground with 10Ω resistance

BLOCK JUDGEMENT

With rapid and powerful calculate capability of modern numerical protection device, this new principle can be engineering practice on REF protection easily. Depneds on the correlation coefficient rage of partition, there can be three zones of calculation correlation coefficient results. Figure 5 below shows these three zones:

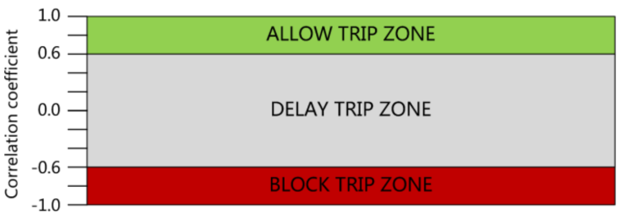

Fig. 5 Three zones of correlation coefficient of REF

First zone is "block trip zone", if the correlation coefficient at -0.6 to -1.0, the protection device must block the REF tripping because of this fault is significant external.

Second zone is "delay trip zone", this zone measure the correlation coefficient is between -0.6 to 0.6, it's fuzz area of judgement and not so significant to be sure is an internal or external fault, so it's necessary to add some delay time for tripping. The length of delay timer depends on the correlation coefficient, the bigger as the correlation coefficient the shorter as the delay timer. In the other side, the smaller as the correlation coefficient the longer as the delay timer.

Third zone is an "allow trip zone", this zone's rage is from 0.6 to 1.0 of the correlation coefficient result. At allow trip zone, it must an internal earth fault happened, so the REF protection have to operate immediately. In this condition the software of device clean the REF trip delay timer counter and release trip command as soon as possible.

RTDS DYNAMIC TEST

For further improve this method, add the algorithm and new logic to numerical protection device CSC-326 transformer protection relay. Then use the real time digital simulator (RTDS) to build a transformer working environment and connect the device for various power system fault simulation. Test item include initial the transformer, internal and external metal fault, internal and external fault with CTs saturation, winding ground fault with resistance, etc. After the whole test, the result reflect the new principle is efficient and reliability. All of slight or heavy CT saturation and unique transfer condition fault test were passed. The REF protection tripped instantaneous at all of the internal earth fault without or with residence.

CONCLUSION

This new method is easily to be actualized through the modern numerical protection device. With powerful computation capability, the numerical relay device using statistic method is becoming realization. This practice mentioned made out a different way to solve some difficulty and complex problems of relay protection. If traditional method like directory, harmonic and detection, couldn't fix the problems, maybe should consider some statistic principle, such as correlation analysis, factor analysis, time serial prediction method and so on. The most important benefit of the statistical analysis principle is that can use full of the current or voltage sampling information and in this way, the device can judge the fault from tend of the current or voltage to increase the accuracy. Modern numerical protection device need to use as much as more information to determine there is an internal or external fault and enhances the performance of relay protection further.

REFERENCES

[1] IEEE, 2008, *IEEE Guide for Protecting Power Transformers*, IEEE Std. C37.91-2008.

[2] B. Nim Taj, A. Mahmoudi, S. Kahourzade, 2011, "Comparison of Low-Impedance Restricted Earth Fault Protection in Power Transformer Numerical Relays [J]", *Australian Journal of Basic and Applied Sciences*. Vol. 5(12), 2458-2474.

[3] ZHU Shengshi, 2003, "Discussion on transformer zero-sequence current differential protection [J]", *Electric Power Automation Equipment*. Vol. 23(10), 5-7.

[4] ZHANG Xiangan, SHAN Qiang, Zhang Xuan, 2005, "Several problems on zero-sequence differential protection for transformer [J]", *Relay*. Vol. 33(15), 13-17.

[5] LUO Xiaoli, ZHAO Anguo, Guo Xiaodong, 2007, "Scheme design of transformer zero-sequence differential protection [J]", *Electric power Automation Equipment*. Vol. 27(7), 119-121.