ON-LINE CONDITION MONITORING OF NON-EFFECTIVELY EARTHED DISTRIBUTION NETWORK USING TRANSIENT EARTH FAULT SIGNALS

Tianyou Li
Fujian Electric Power Co. – China
ltyxm@163.net

Xiantai Zhang
Fuzhou University – China
zhangxiantai8@126.com

Yiyun Guo
University College London–United Kingdom
yiyun.guo.10@ucl.ac.uk

ABSTRACT

The characteristics of temporary single phase grounding fault in a non-effectively earthed system and transient fault signals generated are analyzed. A identification method of fault feeder based on wavelet analysis of transient signals is introduced. A on-line condition monitoring technique using transient fault signals is presented. An condition index indicating the level of insulation deterioration is employed and its calculation method is presented. The proposed technique is verified by the real fault data from Quanzhou network.

Key words: Transient fault signals, Fault line selection method, on-line monitoring for insulation, ageing of line insulation

INTRODUCTION

The insulation level of electric equipment is an important factor affecting safe operation of power grids .Statistics show that insulation failures account for 70% of equipment failures[1]. The traditional on-line condition monitoring system of insulation is not suitable for non-effectively earthed distribution network with various kinds of equipments. Therefore, the condition monitoring of non-effectively earthed distribution network has always been difficult. Analysis to the field recordings of earth faults revealed some of the permanent faults have foreboding temporary faults. The identification of the feeder with transient earth faults provides valuable condition monitoring information.

ANALYSIS OF TRANSIENT FAULT SIGNALS

The insulation of equipment deteriorates at a slow speed under the operation voltage and environment factors such as external mechanical stress, damp, thermal stress and so on[2].The temporary breakdown of external insulation , insulating oil and insulating gas of equipment possibly occurs under normal voltage at the early stage of deterioration. However, the electric arc may extinguish and the insulation may be recovered at zerocrossing of fault current after the water is dried and the impurity is burned out. In another case, the temporary breakdown of some internal solid insulations may possibly occur also when temporary overvoltage exists in network, such as the breakdown of cable insulations because of water tree. However, the insulation can still withstand normal operation voltage after temporary overvoltage disappears at the early stage of insulation deterioration. The temporary insulation breakdown of the feeder with damaged insulation will cause a single phase to ground fault lasting from few milliseconds to several tens milliseconds and produce transient fault signals. The frequency of the temporary breakdown would increase as the insulation deteriorates further. Complete insulation breakdown leads to permanent fault. Therefore the network insulation could be monitored by collecting and analyzing transient fault signals produced in the process of deterioration.

IDENTIFICATION METHOD OF INSULATION DETERIORATION FEEDER

The transient fault signals produced by insulation breakdown contain various frequency components. It is supposed that there are n feeders in a non-effectively earthed medium voltage system, the k-th feeder is the one with deteriorated insulation (hereinafter referred to as faulty feeder) and others are healthy feeders. f_{kc} is the first series resonance frequency of all feeders. By analysis, it is found that the healthy feeder can be replaced with a capacitor for transient components whose frequency is from 0 to f_{kc} . As the sum of the zero-model capacitances of the two longest is normally less than 89% of the total system, the feeders including all healthy feeders and arc suppression coil could be replaced with a capacitor for transient components whose frequency is within the range from 250 Hz to f_{kc} . In this case, transient reactive power flows from fault to bus bar and then to healthy feeders. Accordingly, the direction of transient reactive power flowing in the fault feeder is different from the one in healthy feeders, and its transient reactive power is greater than the one of healthy feeder[3-4], which is shown in Fig.1. In Fig.1, C_{jkq} (j=1,2,…n,j $\neq$ k) is the equivalent capacitance of the j-th healthy feeder, L_{xh} is the inductance of arc suppression coil, Q_j (j=1,2,…n) is the transient reactive power of the j-th feeder, u_{0k} is the zero-model voltage in fault position.

Because there are overhead lines as well as cables in non-effectively earthed system and configurations of operation may change at any time, it is difficult to determine f_{kc} and the frequency range used to identify the faulty line. To solve this problem, wavelet analysis of transient fault signals is employed. The transient fault signals are decomposed to many components which have the same frequency bandwidth by Wavelet Packet Analysis and the frequency band with maximal energy could be determined. Suppose that the left and right boundary frequency of a band is respectively $f_{\max 1}$ and $f_{\max 2}$ .Wave Feature Band(hereinafter referred to as WFB) is defined as frequency range from 250Hz to $f_{\max 2}$,which is shown in Fig.2.

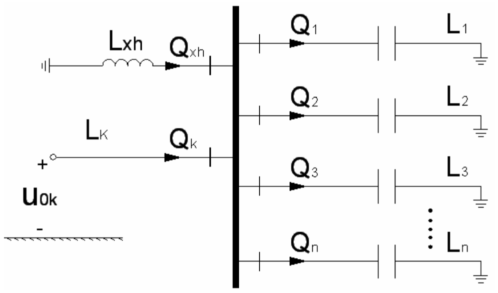


Fig.1 Direction of transient reactive power of feeders when frequency is from 250 Hz to f_{kc} .

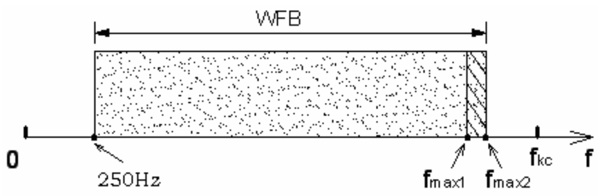


Fig.2 Distribution of WFB

It can be proved that WFB is located within the frequency range from 250Hz to f_{kc} .After WFB is determined, the transient reactive power within WFB of feeders could be calculated to identify the faulty line according to that the direction and amplitude of transient reactive power of faulty feeder are different from all non-faulty feeders.

INSULATION MONITORING MODEL

Insulation monitoring model consists of the identification method of faulty feeder which has been introduced above and the calculation method of deterioration value that is presented as follows.

The following transient insulation parameters which reflect the level of insulation deterioration of feeders are taken into account.

T_{COki} : The duration of the i-th temporary single phase to ground fault. The longer T_{COki} is, the longer the arc duration, which indicates the more severe insulation deterioration.

U_{Oki} : The rms value of zero-model voltage of the i-th temporary single phase to ground fault. The formula of U_{Oki} is the as following:

$$U_{0ki} = \sqrt{\frac{1}{N}\sum_{j=1}^{N} u^{2}{}_{0ki\,j}} \tag{1}$$

where, u_{0kij} is the j-th fault data of zero-model voltage of the i-th temporary single phase grounding. N is the number of samples during T_{COki} .

T_{DSki} : The time interval between the i-th temporary fault and the i-1-th fault.

T_{CLki} : The remaining impact time of the i-th temporary fault for the calculation of deterioration value. The formula of T_{CLki} is as following:

$$T_{CLki} = T_{\max} - T_{ki2} \tag{2}$$

Here, $T_{\max}$ is the maximum set value of remaining impact time (It is generally set to 360 day). T_{ki2} is the time between the calculation time and the i-th temporary fault.

N_{ki} : The accumulative number of faults till the i-th temporary fault within 24 hours.

Based on this transient insulation parameters, an Insulation Deterioration Value(hereinafter referred to as IDV) of the k-th feeder is defined as follows.

$$\begin{aligned} IDV_k &= \sum_{i=1}^{N_{zk}} U_{0ki} \times \left(T_{COki}/10\right)\left[\frac{\left(T_{CLki}/360\right)\times N_{ki}}{\left(T_{DSki}/30\right)} \times A_f\right] \\ &= \frac{1}{120}\sum_{i=1}^{N_{kz}} U_{0ki} T_{COki} \frac{T_{CLki}\times N_{ki}}{T_{DSki}} A_f \end{aligned} \tag{3}$$

where, N_{sk} is the accumulative times of faults since the beginning of calculation. A_f is influence factor, generally set to 0.1.The units of T_{COki} , T_{DSki} , U_{Oki} and T_{CLki} are ms, day ,kV and day respectively. The constants (10,360 and 30) are used to reduce the effects of different parameters.

In order to improve the visualization and manoeuvrability of insulation monitoring model, a threshold of insulation deterioration (IDV_{set}) is set. Insulation Deterioration Index (hereinafter referred to as IDI) is defined as follows.

$$IDI_k = IDV_k \ / \ IDV_{set} \qquad (4)$$

When IDIk >1, the monitoring model will warn that the insulation of the k-th feeder has deteriorated seriously and this feeder should be inspected to find and eliminate the hidden insulation problem.

VERIFICATION OF MONITORING MODEL BASED ON THE REAL FAULT DATA

The real fault data from DP feeder of CD substation, Quanzhou, Fujian are used to verify the monitoring model. The fault phenomenon is the breakdown of a porcelain insulator. It was found that the porcelain insulator had cracks and flashover traces before permanent fault. The month distribution of temporary single phase to ground fault is shown in Fig.3.

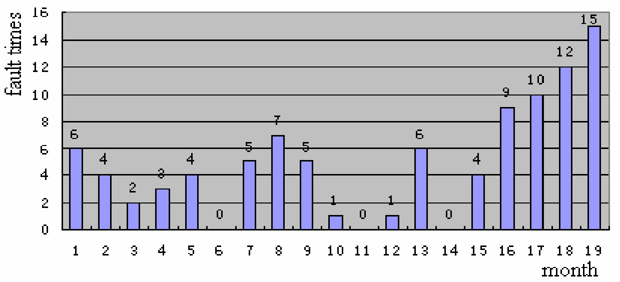
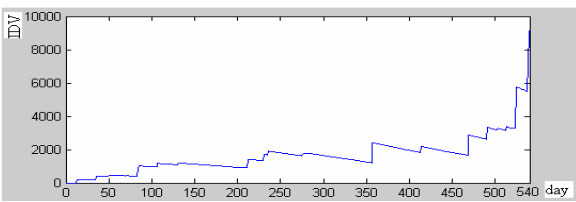
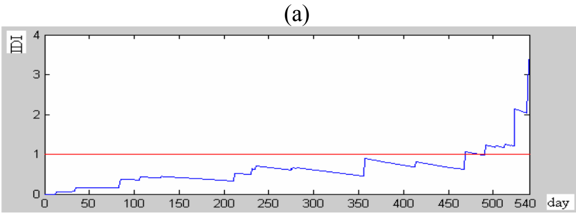


Fig.3 Distribution of instantaneous single phase grounding fault of DP feeder

The times of temporary single phase to ground fault is not regular before the fifteenth month from Fig.3,but they increase significantly after fifteenth month. The insulation of DP feeder severely deteriorated and led to a permanent fault at nineteenth month. DP feeder could be identified as faulty feeder using the identification model and the transient insulation parameters could be calculated when every temporary single phase to ground fault occurs .Then IDV and IDI of DP feeder for each day could be obtained based on the formula 3 and formula 4, as shown in Fig.4.



(a)



(b)

Fig.4 (a) IDV of DP feeder (b) ID I of DP feeder

The real fault data in 540 days before the permanent fault in DP feeder is used to calculate the IDV and IDI for each day. The IDV increases gradually on the whole from Fig.4(a),and shows an accelerative trend in later part. In Fig.4(b), the IDI of DP feeder exceeds the red line at the 469th day, being greater than 1, which means that the insulation of DP feeder has deteriorated seriously. Accordingly, if this monitoring model had been used to calculate the IDI of DP feeder and to indicate that the insulation had deteriorated seriously at the 469th day , DP feeder would have been inspected to find and eliminate the hidden insulation problem of porcelain insulator. The complete loss of insulation property of porcelain insulator and the permanent fault of DP feeder at the 540th day would have been avoided.

CONCLUSIONS

Based on the theoretical analysis and real fault data it is proved that temporary single phase to ground fault occurs occasionally at the initial stage of insulation deterioration in non-effectively earthed distribution network, and the frequency of temporary fault is not regular. However, the frequency increases obviously at the later stage of insulation deterioration, which indicates that the insulation deterioration accelerates. The IDI usually exceeds 1 several months before permanent fault. The theoretical analysis and verification of the monitoring model using 22 permanent faults (The other 21 permanent faults are not introduced in this paper) show that the proposed monitoring model could effectively monitor the deterioration of feeder insulation and the feeder with weak insulation can be identified reliably.

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