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DFT를 이용한 송전선로 적응적 단상재폐로 방안에 관한 연구

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A Study on the Adaptive Single Pole Auto-Reclosure Techniques for Transmission Lines Based on Discrete Fourier Transform

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Abstract - This paper presents a new numerical algorithm suitable for defining recloser reclaims time and blocking automatic reclosing during permanent faults on overhead lines. It is based on terminal voltage input data processing. The decision if it is safe or not to reclose is determined from the voltage signal of faulted and tripped line phase using Total Harmonic Distortion factor calculated by Discrete Fourier Transform. The algorithm was successfully tested using signals recorded on the real power system. The tests demonstrate the ability of presented algorithm to determine the secondary arc extinction time and to block unsuccessful automatic reclosing of HV lines with permanent fault.

1. Introduction

Automatic reclosing(AR) of overhead lines was conceived to improve electric power security during disturbances caused by transient line faults [1-5]. Where dynamic stability is a concern then single pole tripping with high speed autoreclose(HSAR) is employed to overcome single phase to ground faults, which constitute the majority of network faults. Three pole tripping and delayed autoreclosing(DAR) is widely employed to restore transmission capacity or lost supplies and can respond to any fault type.

The simple principle of AR is to reclose after a set time delay following a protection trip. These reclosing is not optimized to line conditions e.g. there may be an unnecessary delay after deionisation of the fault path during which dynamic stability is at risk or further faults occurring during recloser reclaim time, such as may occur during lightning storms, are judged to be a repeat of the original fault (i.e. a permanent fault), and further reclose is locked out.

To overcome these risks and to optimize and adapt single pole AR to line conditions the new numerical algorithms is derived by this research.

2. Algorithm Derivation

It is necessary to study all characteristic phases of single pole to ground fault on a transmission line. Fig.1 shows the transmission line with single pole to ground fault. The fault can be either temporary or permanent. Temporary faults are followed by an electric arc. During fault faulted conductor current(I_f) increases and voltage decreases.

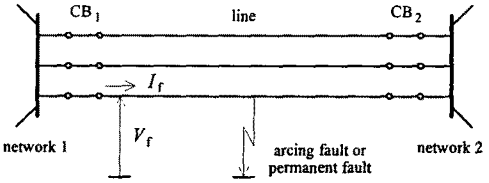

Fig.1 Line with a temporary or a permanent fault

Fig.2 shows the transmission line with single phase to ground fault and opened faulted phase conductor. The input current of faulted conductor is zero($I_{0f}=0$). Faulted phase conductor has no galvanic connection with voltage source; it is connected with other phase conductors by mutual capacitance. This connection feeds fault current and supports the fault arc, which is called the secondary arc.

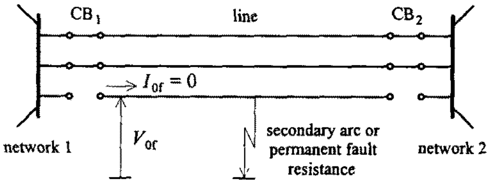

Fig.2 Line with opened faulted phase conductor

The voltage of opened phase depends on the fault place and the fault resistance. The secondary arc current is small. It is not able to support the secondary arc for a long time. After some time the secondary arc disappears. That is why the secondary arc is unstable. When the secondary arc disappears, temporary fault disappears, too.

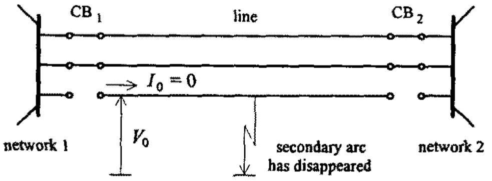

Fig.3 Post-secondary arc period

Fig.3 shows the transmission line with opened faulted phase conductor without the secondary arc (secondary arc has disappeared). Conductor voltage increases. This phase of single pole to ground fault may occur only in the case of a temporary fault.

In the case of a permanent fault the opened conductor is connected with the ground through permanent fault resistance. The voltage cannot be returned to the faulted phase. The transmission line must be completely switched off.

The Discrete Fourier Transform (DFT) is a discrete time version of the Fourier Transform. The result of this algorithm is referred to as phasor quantity. The equation for the calculation of the phasor representing root mean square value of the h-th order harmonic is:

$$V_h = \frac{\sqrt{2}}{N}\sum_{k=0}^{N-1}\left(v_k \cos\frac{k2\pi h}{N} - j\, v_k \sin\frac{k2\pi h}{N}\right) \quad (1)$$

where h is the harmonic number, k is the sample, N is the number of samples per cycle, and j means it is an imaginary number.

Squaring the real part, squaring the imaginary part, summing the squared values and taking the square root find the magnitude of h-th order harmonic.

$$V_h = |V_h| = \sqrt{Re^2(V_h) + Im^2(V_h)} \quad (2)$$

From the practical reasons, total harmonic distortion factor was calculated using only harmonics up to 5-th order:

$$THD(\%) = \frac{\sqrt{\sum_{h=2}^{5} V_h^{\,2}}}{V_1} * 100(\%) \quad (3)$$

During secondary arc period THD(%) has great value. During period after secondary arc extinction THD(%) has small value. Rapidly decrease of THD(%) defines the inception of period after secondary arc extinction.

It is possible to conclude that the moment of the secondary arc extinction is defined by decreasing the THD(%). Before starting the algorithm presented, one has to select the sampling frequency f_s and the number of samples N (i.e. the duration of data window T_{dw}). It is common to select T_{dw} to be equal to T_0, where T_0 = 0.02 s, and f_s = 1600 Hz (32 samples/T_0).

3. Testing and Results

In order to check the validity of the algorithm presented, data recorded in high voltage substations of transmission network are used. One of them is presented in Fig.4 and 5.

In Fig.4 the voltage of faulted phase conductor during single pole to ground fault with short secondary arc period is presented. In Fig.5 recorded current is depicted.

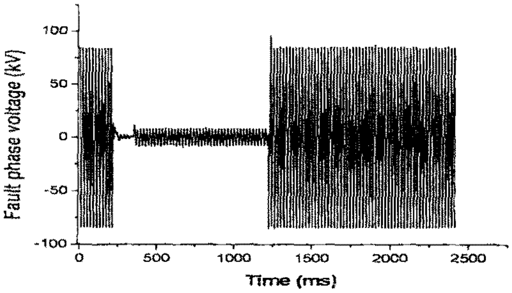

Fig.4 Fault phase voltage on 100kV transmission line with short secondary arc

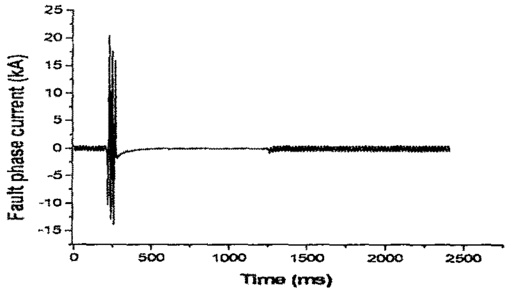

Fig.5 Fault phase current on 100kV transmission line with short secondary arc

By processing voltage shown in Fig.4, the THD(%) is calculated and shown in Fig.6. Fig.6 clearly shows that the THD(%) decreasing define the moment of the secondary arc extinction. In the Fig.7 the output of adaptive reclosure is shown.

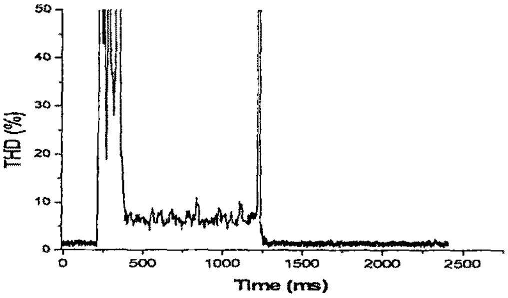

Fig.6 Value of Criterion function calculated from the voltage shown Fig.4

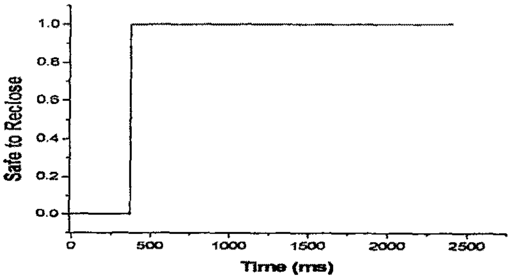

Fig.7 Output of adaptive reclosure from the voltage shown in Fig.4

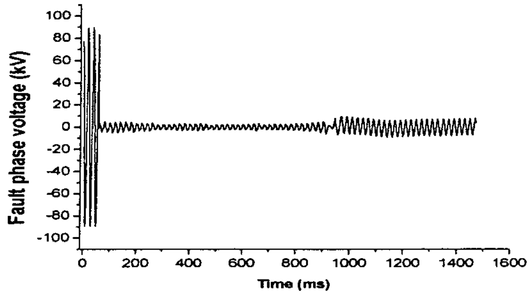

Fig.8 Fault phase voltage on 100kV transmission line with long secondary arc

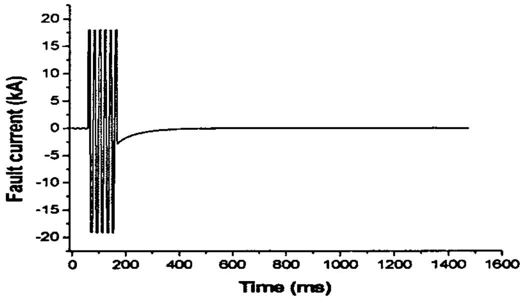

Fig.9 Fault phase current on 100kV transmission line with long secondary arc

In Fig.8 and Fig.9 the voltage and current of faulted phase conductor during single pole to ground fault with long secondary arc period are presented. The outputs of presented algorithm are shown in Fig.10 and Fig.11.

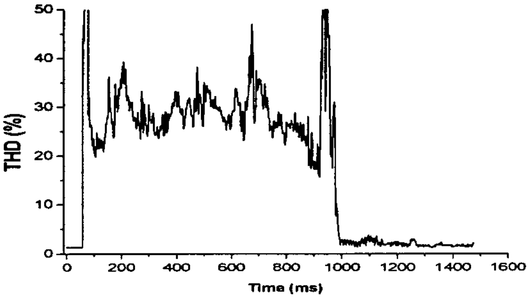

Fig.10 Value of Criterion function calculated from the voltage shown Fig.8

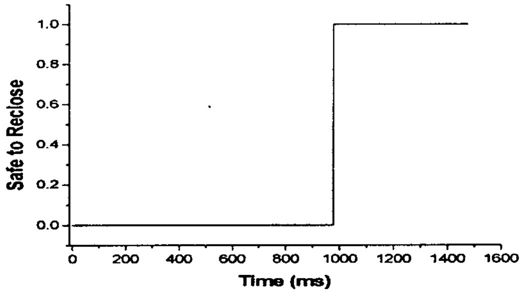

Fig.11 Output of adaptive reclosure from the voltage shown in Fig.8

When considering the speed of the algorithm convergence, one concludes that it is fast enough from the automatic reclosure point of view. The reliable information of the secondary arc disappearing can be obtained in 20ms upon the secondary arc extinction.

The automatic reclosure technique based on the defined recloser reclaim time is not optimal. In many cases of temporary single pole to ground faults this recloser reclaim time is needlessly long. Fig.9 shows that needed recloser reclaim time is only 160ms. The needed recloser reclaim time is 6.25 times shorter than adjusted recloser reclaim time equal to 1 s.

4. Conclusion

A numerical algorithm for blocking automatic reclosing on transmission lines with single pole to ground faults is presented. It can be utilized in the field of the line distance protection. Through analyzing data recorded in high voltage substations of a transmission network it is concluded that the algorithm is very accurate and fast enough to be used for blocking automatic reclosing. The algorithm presented operates using only one input signal, voltage of faulted phase conductor. It is able to determine the optimum length of recloser reclaim time in the case of temporary fault on the single or double lines. In the case of permanent fault the algorithm presented blocks automatic reclosing and locks out reclosing onto permanent fault.

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