Incipient Fault Detection in Medium Voltage Underground Power Cable

Sibin K.
PG Student, *Dept. of Electrical Engineering Govt.Engineering College Thrissur,* India

Mini V.
Assistant Professor, *Dept. of Electrical Engineering Govt.Engineering College Thrissur,* India

Abstract—The medium voltage types of underground power cables will exhibit incipient faults. They often go undetected and eventually result in a permanent fault causes load losses. Such faults can be classified into two types, subcycle and multicycle incipient faults. Sub-cycle types of incipient faults last only for a one-quarter cycle and clear itself at their first current zero point. Multi-cycle types of incipient fault are also a self-clearing fault that may last for one to many cycles. But, if they are left undetected for their initial time of propagation, they may result in permanent faults. This paper is mainly focused on multicycle incipient faults and their detection in a medium voltage underground power cable. A typical incipient fault is modelled as a self-clearing fault, and its voltage distortion degree is utilized to identify the presence of an incipient fault. The proposed methodology has been simulated and verified in a PSCAD/EMTDC platform.

Keywords— *incipient fault, arcing fault, incipient fault detection, medium voltage underground power cable*

I. INTRODUCTION

In this modern scenario, underground(UG) cables have been widely used in electric power transmission and distribution networks due to its several advantages. It includes the provision of underground connections, security over overhead power lines, less liable to the storms and lightning, less expensive for a shorter distance, low maintenance, and environment-friendly. The normal faults in UG cables can be categorized into two types: incipient faults and permanent faults. Incipient faults are a low magnitude &fastly dying transients, which are lasts lasting only for few micro to milli-seconds. Such faults can be classified into two types, subcycle, and multicycle incipient faults. Subcycle faults last for 1/4 cycles and they self-clears at zero current crossing points. Multicycle faults are of which lasts for more than 1 cycles. Though they last for only a few cycles, it is difficult to detect such faults with traditional overcurrent relays. That is, they are incapable of detecting this small duration, small amplitude arcing faults. [1]–[4]. In practical cases, it is observed that up to 15% of the total faults in a cable are initiated by incipient faults. So, it is required to detect and locate these faults in the UG cables at the earliest stage. As said mentioned earlier, if they were left undetected, they become a permanent fault while traveling through the transmission line. So, in order to reduce the chances of occurrence of permanent faults in the underground cables, it is required to detect the incipient faults. Also, comparing with the arc fault detection methods in overhead lines, less studies are done in underground power cables.

A distinctive incipient fault is composed of two types: sub-cycle and multi-cycle incipient fault. The sub-cycle type of incipient fault always occurs near the peak voltage where the arc is initiated, and they last around one-quarter cycle only and clear itself when the current first crosses the output zero point. The substation-end current waveforms of a three-phase feeder is shown in the figure. It is a single phase to ground incipient fault occurs between phase A and ground. The multicycle types of incipient fault also occur near the peak voltage, but it lasts for 1 to 4 cycles and clears when the arc is extinguished. The current waveforms of both subcycle and multicycle incipient fault currents are shown in fig.1 and 2. It can be observed that the current shoots to a higher value when the fault is ignited. It lasts for only a few cycles and comes to the normal state within a small interval of time. Also, the amplitude value is not much higher than the conventional faults.

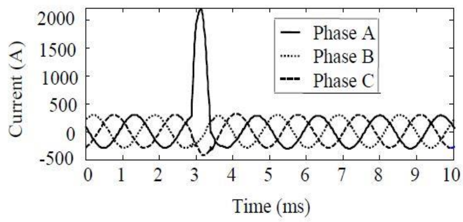

Figure 1: Current waveform of Sub-cycle type of incipient fault.

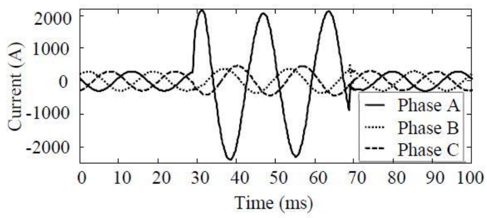

Figure 2: Current waveform of Multi-cycle type of incipient fault

Relatively small magnitude fault currents and the short duration (going from one-quarter cycle to many cycles) are the main characteristics of an incipient fault. Though they are in low magnitude and of short duration, conventional over current relays cannot detect or pick up these kinds of faults. However, it is required to detect these incipient faults at the initial stage to evade the resultant disaster caused by this arcing fault. The mitigation of incipient faults can offer an initial stage caution message for the failure of the faulty cable, even trip the respective section to limit the continuous voltage disturbances.

The basic procedure for the detection of an incipient fault is to study the features of different parameters like voltages and currents in the time domain, frequency domain, and both time-frequency domain.

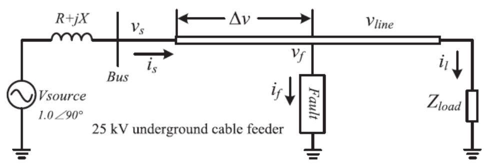

Fig.3 Simplified Cable fault model

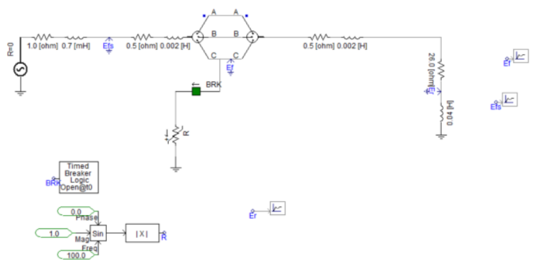

Fig. 4 Simulation model for a simplified fault in 25kV line

Normally, the incipient faults are incorporated with an arcing fault [1]–[4],[6]. Meanwhile, an arc is an indispensable characteristic of an incipient fault; this paper suggests an arcing fault detection centred incipient fault location and detection method. There are many methods have been proposed for arcing fault detection, as well as high impedance fault (HIF) detection [9] and transient fault identification [10]–[12]. The HIF detection was established based on fault current distortion feature [9]. Practically the arcing fault current in an underground power cable has a little distortion [13]. Thus the arc voltage distortion characteristic is more appropriate for arcing fault detection in underground power cables. In papers [10] and [11], the arc voltage was represented by an ideal square waveform. The detection was done according to the amplitude values of the expected square wave obtained from the substation end signals. Though the rectangular waveform model may not fully describe arcing fault and thus the wrong detection may be happening. In paper [12] an arcing fault voltage of rectangular form is modelled as a source of harmonics, and the total harmonic distortion (THD) of the substation end voltage was used for the detection. But the amount of voltage distortion is very small at the substation end.

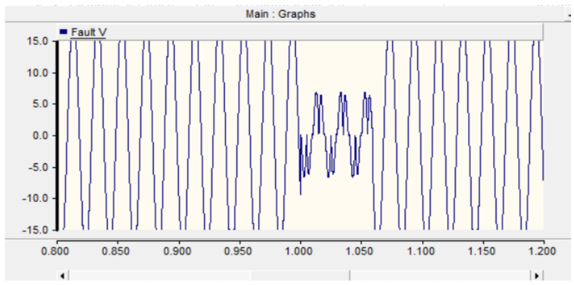

Fig. 5 Voltage waveforms of a multi-cycle,arcing fault measured at fault point

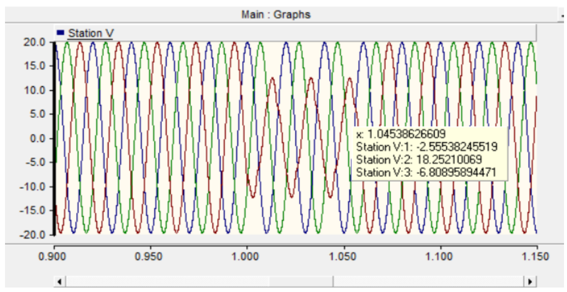

Fig. 6 Voltage waveforms of a multi-cycle arcing fault measured at fault point.

II. FAULT MODEL ANDARC FAULT CHARACTERISTICS

This proposed technique is used for identifying a multi-cycle incipient fault from plenty of other possible instabilities and for finding the distance of the fault. Here is a simplified model of a fault is introduced, which can be used to explain the characteristics of an incipient fault and to mitigate the fault in the underground power cables.

The bus voltage will change when a fault is introduced in the underground power cable. The substation end voltage at the time of fault is given by the bus voltage equation Vs (t). Vs(t) can be represented as:

$$vs\ (t) = \Delta v(t) + vf\ (t)$$

$$= i_s(t).R + L.\,{}^{di(s)}/_{dt} + V_f(t) \quad (1)$$

whereΔv(t) is the cable voltage drop along, vf (t) is the voltage at the fault point, is (t) is the value of feeder current, D is the current fault distance (km), L and R are the corresponding inductance and resistance values of the underground cable per unit length respectively.

A simplified underground cable fault model is given in fig.3. It is medium voltage 25 kV cable feeder connected between the substation and the receiving end. An arcing fault is introduced in the middle of the cable, such that corresponding fault currents and voltages are plotted. In an underground power cable, an incipient fault is a special kind of arcing fault in which they were self-clears at their first zero point crossing current [1]–[4]. Fig. 5 shows a simplified model of a cable fault. The voltage waveforms of an incipient fault are visualised in it. From the figure 4 and 5, we can see that the shape and characteristics of an arcing fault are nearly same as that of a distorted square wave. This characteristic was also noted in [6], [10], [11]. The instantaneous voltage waveform of an incipient fault is slightly non-linear with the high amount of harmonics. This voltage can be utilized to detect the presence of the fault.

The voltage drop on the transmission line plays a vital role in the detection of an incipient fault at the substation end. The transient rectangular waveform of the incipient fault is smoothed by the effective voltage drop (Δv) of the line. That is in the fig. we can see a distorted rectangular waveform at the fault end. When the wave propagates through the line, the distortion is levelled and smoothed, the distortion measured at the fault point has vanished, a sinusoidal waveform can be observed at the substation end. Though the distortion of the voltage, current waveforms are not reflected at the substation end, we cannot detect the presence of the incipient fault early. This is one of the characteristic of incipient fault, in which it gets unnoticeable in normal cases.

III. THE PROPOSED FAULT DETECTION AND DISTANCE ESTIMATION IDEAS

The arcing fault can be identified from the nature of fault point voltage. From the equation (1) the fault point voltage Vf(t) can be found as follows.

$$Vs\ (t) = \Delta v(t) + Vf\ (t)$$

$$= i_s(t).R + D\ [L\ .\ {}^{di(s)}/_{dt} + V_f(t)]$$

$$Vf\ (t) = vs\ (t) - D\ [\ i_s(t).R + L.{}^{di(s)}/_{dt}] \qquad (2)$$

A set of fault point voltage Vf (t) waveforms can be obtained from the derived equation of Vf (t) for all fault distances by setting different values for D, setting from D= 0.1 to the total length l. If the value of D matches the actual fault location, the fault voltage exhibits a large distortion that has the features of a rectangular wave.

To evaluate the amount of voltage distortion occurred in the voltage waveform, fast Fourier transform (FFT) is adopted to analysis vf (t) and the corresponding voltage total harmonic distortion (THD) is find out. Fig. 6 shows the amount of fault point voltage THD (VTHD) for different values of fault distances. It is clear from the figure that, the fault point voltage total harmonic distortion varies according to the fault distances. The presence of an arcing fault/ incipient fault can be identified from the points at which the VTHD is larger than the fixed threshold fault distance. This is because there will be only a small amount of distortion will be present for other types of faults. So the chances of false alarm are very small in this proposed detection method.

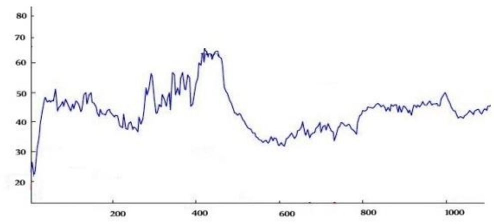

Fig. 6 The arc voltage THD

IV. RESULTS AND DISCUSSIONS

From the diagrams, we can see that the arc fault voltage looks like a rectangular waveform at the fault point. Also, the distorted rectangular wave visible at the fault point has vanished, and a nearly sinusoidal waveform is present at the substation end. The arc voltage distortion feature is utilized for the accurate detection of the arcing fault. The voltage waveform shows a voltage dip in at the fault point. Likewise, a corresponding current shoot is present in the fault point current waveforms. This method measures both the voltage and currents at the substation end; it is used for the proposed fault detection scheme.

V. CONCLUSION

This paper put forward a novel method to find the incipient fault detection in underground power cables. It is an arcing fault centred multi-cycle incipient fault revealing the method for medium voltage underground power cable. By closely watching the incipient fault voltage, it is observed that the arc voltage has a heavy alteration like a square waveform at the substation end. When the fault distance is very large, as it travels through the cable, the voltage measured at the feeder end is almost sinusoidal. A new detection method is introduced by calculating the fault point voltage and current, and fault point voltage THDs for all probable values of fault distances. Some additional parameters are required to be measured and modelled in order to precisely find the fault distance.

REFERENCES

[1] B. Kasztenny, I. Voloh, and C. G. Jones, "Detection of incipient faults in underground medium voltage cables," in Proc. Power Syst. Conf., 2009, pp. 1–12.

[2] N. T. Stringer and L. A. Kojovic, "Prevention of underground cable splice failures," IEEE Trans. Ind. Appl., vol. 37, no. 1, pp. 230–239, Jan./Feb. 2001.

[3] R.Moghe,M. J.Mousavi, J. Stoupis, and McGowan, "Field investigation and analysis of incipient faults leading to a catastrophic failure in an underground distribution feeder," in Proc.PowerSyst.Conf.Expo., Seattle,WA, USA, 2009, pp. 1–6.

[4] T. S. Sidhu and Z. Xu, "Detection of incipient faults in distribution underground cables," IEEE Trans. Power Del., vol. 25, no. 3, pp. 1363–1371, Jul. 2010.

[5] M. J. Mousavi and K. L. Butler-Purry, "Detecting incipient faults via numerical modeling and statistical change detection," IEEE Trans. Power Del., vol. 25, no. 3, pp. 1275–1283, Jul. 2010.

[6] S. Kulkarni, S. Santoso, and T. A. Short, "Incipient fault location algorithm for underground cables," IEEE Trans. Smart Grid, vol. 5, no. 3, pp. 1165–1174, May 2014.

[7] T. T.Newton and L.Kojovic, "Detection of sub-cycle, self-clearing faults," U.S. Patent 6198401, Mar. 6, 2001.

[8] J. Stoupis, A. C. Madwesh, and D. Lubkeman, "Cable fault detection," U.S. Patent 7672812. 2, Mar. 2010.

[9] M. Sedighizadeh, A. Rezazadeh, and N. I. Elkalashy, "Approaches in high impedance fault detection a chronological review," Adv. Elect. Comput. Eng., vol. 10, no. 3, pp. 114–128, 2010.

[10] M. B. Djuric and V. V. Terzija, "A new approach to the arcing faults detection for fast autoreclosure in transmission systems," IEEE Trans. Power Del., vol. 10, no. 4, pp. 1793–1798, Oct. 1995.

[11] V. V. Terzijaand Z. M. Radojevic, "Numerical algorithm for adaptive autoreclosure and protection of medium-voltage overhead lines," IEEE Trans. Power Del., vol. 19, no. 2, pp. 554–559, Apr. 2004.

[12] Z. M. Radojevic and Joong-Rin Shin, "New digital algorithm for adaptivereclosing based on the calculation of the faulted phase voltage total harmonic distortion factor," IEEE Trans. Power Del., vol. 22, no. 1, pp. 37–41, Jan. 2007.

[13] B. Koch and P. Christophe, "Arc voltage for arcing faults on 25 (28)-kV cables and splices," IEEE Trans. Power Del., vol. 8, no. 3, pp. 779–788, Jul. 1993.

[14] J. Barros, M. Apraiz, and R. I. Diego, "Review of signal processing technique for detection of transient disturbances in voltage supply systems, in Proc. IEEE Int. Instrum. Meas. Tech. Conf., Minneapolis, MN USA, 2013, pp. 450–455.

[15] A. Ferrero and S. Salicone, "An easy VI program to detect transient disturbances in the supply voltage," IEEE Trans. Instrum. Meas., vol. 54 no. 4, pp. 1471–1474, Aug. 2005.