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RURAL ELECTRIC DISTRIBUTION SYSTEMS FAULT DETECTION USING HIGH IMPEDANCE TECHNIQUE

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ABSTRACT: The detection of high impedance faults on electrical distribution systems has been one of the most persistent and difficult problems facing the electric utility industry. Recent advances in digital technology have enabled practical solutions for the detection of a high percentage of these previously undetectable faults. This paper reviews several mechanical and electrical methods of detecting high impedance faults. The significance of these previously undetectable faults is that they represent a serious public safety hazard as well as a risk of arcing ignition of fires. High impedance faults produce current levels in the 0 to 50 ampere range. Typically, HIF exhibits arcing and flashing at the point of contact. Throughout the utility industry, there have been differences of opinion on how often HIFs occur. Normally, utilities do not keep good records on the number of down conductor instances.

KEYWORDS: PSRC, HIF, Transient analysis, harmonics, real

1. INTRODUCTION

This is a status report to the Line Protection Sub-Committee of the PSRC on the applications of high impedance fault detection technology. Not all unsafe conditions involve a HIF, i.e. a sagging conductor. This paper does not address the detection of those abnormal conditions where a conductor breaks and does not contact either another conductor or a grounded element. A high impedance fault (HIF) does not have to involve a path to ground and, in fact, whether a ground is involved does not matter to the HIF detector. A high impedance fault can exist between two phase conductors (a tree limb lying across two phase conductors). The majority of HIFs do involve ground. In this discussion, high impedance faults will be referred to as HIFs whether or not ground is involved. A high impedance ground fault results when a primary conductor makes unwanted electrical contact with a road surface, sidewalk, sod, tree limb, or with some other surface, or object which restricts the flow of fault current to a level below that reliably detectable by conventional over current devices. Often this leaves a conductor energized on the ground surface posing a danger to the public. The nature of HIFs has been studied since the early 1970's with the hope of finding some characteristic in the current or voltage waveform that would make detection possible and practical. It is seldom recorded on trouble reports unless it results in a fuse or breaker operation. While it is likely that only a few percent (5-20%) of all distribution faults are high impedance faults, means exist to detect a high percentage of HIFs. The detection of high impedance faults on rural electrical distribution systems has been one of the most persistent and difficult problems facing the electric utility industry. Advances in digital technology have enabled practical solutions for the detection of a high percentage of these previously undetectable faults. This paper will review several methods of detecting high impedance faults. The issues and application of this technology will also be discussed. Field experience using digital technology will be also reviewed.

2. HIGH IMPEDANCE FAULT DETECTION

Energy demand in the pre - industrial world was provided mostly by man and animal power and to a limited extent from the burning of wood for heating, cooking and smelting of metals. The discovery of abundant coal, and the concurrent technological advances in its use, propelled the industrial revolution. Steam engines, mechanized production and improved transportation, all fuelled directly by coal, rapidly followed. The inter war years saw the rise of oil exploration and use. Access to this critical fuel became a key issue during the Second World War. Post - war industrial expansion and prosperity was increasingly driven by oil, as was the massive growth in private car use. More recently a new phase of economic growth has been underpinned to a great extent by natural gas. A substantial proportion of coal and gas production is used to generate electricity, which has been widely available now for over a century. Electricity is a premium form of energy due to its fl exibility and ease of distribution. Demand worldwide is growing, driven by the explosion in consumer electronics, the associated industrial activity and the widening of access to consumers in the developing world. Detection of downed power lines is a long-standing problem to electric utilities. High impedance faults result in very low currents which are often not detectable by conventional overcurrnet relays. A HIF occurs, for example, when a conductor breaks and falls on a no conducting surface such as asphalts road, sand, grass or a tree limb producing a very small current. These faults are difficult to detect when the impedance at the point of fault is high enough to limit the fault current to the region unprotected by conventional over current devices (Fig. 1).

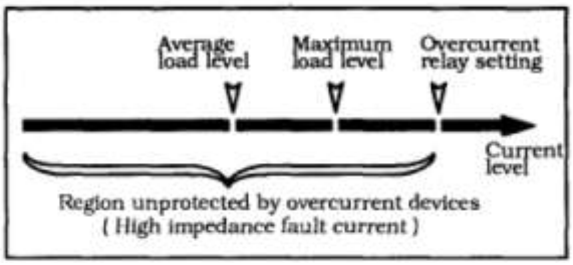

Fig.1: Relation of high impedance fault current to over current

When no solid return path for the current is available, the fault exhibits arcing phenomena; these faults are then referred to as “high impedance arcing faults”. HIFs are a dangerous phenomenon since risks of electric shocks are posed to the public and fire hazard also exist. It is estimated that majority of electrically caused fires are due to arc type, hot neutral intermittent faults [1] . Therefore, the principal motivation in high impedance fault detection is not just system protection, but to improve safety. The threshold of overcurrnet relays must be set at a relatively high current level to prevent tripping by inrush currents thereby causing unnecessary service interruption. Most detection schemes involve the adjustment of the existing over current protection to be more sensitive by lowering its setting. Such schemes have failed to operate in 32% of high impedance faults and lead to several unexpected service interruptions [1].

In the past two decades many techniques have been proposed to improve the detection of HIFs in power distribution systems, and recently the utilities have intensified research programs searching for more efficient protection against this type of a fault. Some of the techniques used to deal with this problem are mechanical methods where various mechanical devices are used to provide a low impedance fault by catching the fallen conductor [2]. Others have used electrical methods and techniques

3. ARC CURRENT NATURE

An arc is defined as a luminous electrical discharge flowing through a gas between two electrodes. In the case of an arcing HIF, when an energized conductor touches the ground, the electric contact is not solid. Due to the existence of air between the ground and the conductor, the high potential difference across a short distance excites the appearance of an arc. Many authors have worked on the theory and dynamics of voltages and currents in an electric arc, most such studies are experimentally based. In [15] and later in [16] a model explaining the phenomenon using a spark gap was proposed. This air gap will not conduct till the applied voltage reaches the breakdown point. Then the current flows and reaches a maximum when the applied voltage equals the arc voltage. After that, the arc current decreases and becomes zero, i.e. the arc is extinguished. When extinction occurs, the arc requires a potential, known as restrike voltage, to reignite. This reignition will have the opposite polarity. This explains the typical voltage-current waveform of an arc shown in Fig. 2. Many electric models have been proposed describing arc behaviour as reviewed by [17]

In the context of downed conductors, Russell [18] conducted staged HIF tests studying dependencies of arc current magnitude on potential difference, gap distance, features of the grounding surface and environmental conditions of the grounding point. A high degree of random behaviour was observed due to impurities near the grounding point, heat from the arc that is intense enough to fuse substances and the evolution of different paths for current flow on surfaces. Some previous researchers have reached a consensus that HIFs are nonlinear and asymmetric, and that modelling should include random and dynamic qualities of arcing. Emanuel et al [19] suggested two dc sources connected anti parallel with two diodes to simulate zero periods of arcing and asymmetry.

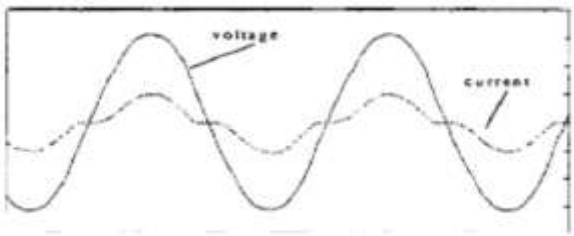

Fig.2: Electric arc voltage and current shapes

Yu et al [20] used combinations of nonlinear resistors, while Wai et al [21] introduced a sophisticated TACS switch controlling the open/closed loop of a HIF to introduce nonlinearity and asymmetry. In this paper, a more dynamic and random HIF model is applied. It combines most of the advantages of the previous models proposed while remaining simple and universal; it was first put forward by the authors in [22]. The high impedance fault model proposed in [22] is shown in Fig. 3 and includes two DC sources, Vp and Vn, which represent the arcing voltage of air in soil and/or between trees and the distribution line; two resistances, Rp and Rn, between diodes, which represent the resistance of trees and/or the earth resistance; and since most observed arcs occur in highly inductive circuits two inductances, Lp and Ln, added to the circuit.

The effect of the inductances leads to the nonlinearity loop in the V-I curve and the desired asymmetrical shape for the HIF current. When the line voltage is greater than the positive DC voltage Vp, the fault current starts flowing towards the ground. The fault current reverses backward from the ground when the line voltage is less than the negative DC voltage Vn. In the case when the line voltage is in between Vp and Vn, the line voltage is counterbalanced by Vp or Vn so that no fault current flows. As a direct result of the presented model the typical high impedance fault current and V-I curves were produced and are shown in Figures.

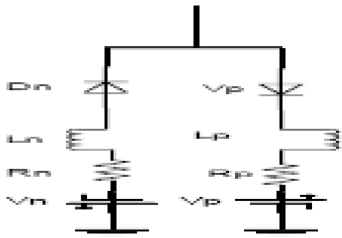

Fig. 3: A two diode fault model for a HIF containing *Rn, Rp, Ln, Lp*

When a conductor is left energized on the ground, it represents an increased hazard to the public in the immediate vicinity of the downed wire. Therefore, the solution appears to be obvious - employ HIF detection and clear the circuit immediately for such conditions. Unfortunately, the decision is not that simple. No device, overcurrent or otherwise, can protect from initial electrical contact. The type of HIF detection currently available is relatively slow. Therefore, its ability to prevent and protect against an injury resulting when the downed conductor event and the occurrence of electrical contact close together is limited.

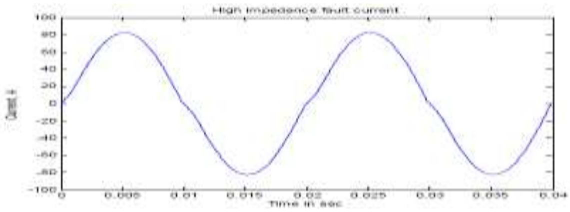

Fig.4. Current curve for HIF

The harmonic model

A signal can be defined as a function that carries information, usually about a state or a procedure of a physical system. However, signals can be represented in several ways. Mathematically, a periodic and distorted signal can be suitably represented in terms of its fundamental frequency and harmonic components, expressed as a sum of sinusoidal waveforms referred to as the Fourier series. Each frequency is an integer multiple of the fundamental system frequency. In order to obtain an approximation of such waves, mathematical models are employed. Consider a current waveform with harmonic components, written as [22]

4. CONCLUSION

A new method for high impedance fault detection is proposed. The problem is formulated as an estimation task and a Real simlink model is used to solve this optimization problem. The method was successfully tested on tracking harmonics and current angles associated with HIF. The very accurate results obtained show that the proposed approach can be used as a very reliable method of identifying high impedance faults.

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