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Detection of Faults on Rural Electric Distribution and Power Quality Control Systems Using High Impedance

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ABSTRACT: Individual devices, such as recloser controls, voltage regulator controls, capacitor controls, and faulted circuit indicators, but today, integrated systems connect these devices into a complete system. Advancements in both local and remote communications have afforded methods to use information from completely different devices to automate the grid for improved Power quality reliability and efficiency. For example, voltages measured at a regulator out on the network can be used by a distribution automation controller to control a capacitor bank in the substation for optimum feeder efficiency. It is now more than a decade since distributed generation began to excite major interest amongst electric power system planners and operators, energy policy makers and regulators as well as developers. This paper presents an overview of the key issues concerning the integration of distributed generation into electric power systems that are of most interest today.

KEYWORDS*: Voltage regulator, High-impedance, high potential

I. INTRODUCTION

High-impedance faults (HIFs) on distribution feeders are abnormal electrical conditions that cannot be detected by conventional protection schemes. These faults pose a threat on human lives when neighboring objects become in contact with the line's bare and energized conductors. An accurate electrical model for a HIF is implemented to investigate typical patterns in the line's current that allow for the detection of these faults. The occurrence of HIFs is detected with harmonic-current phase analysis and localized with recloser-sectionalizer technology as presented in this work. A sectionalizer algorithm is then presented showing the decision criteria for HIF declaration Distribution feeder conductor's are prone to physical contact with neighboring objects such as overgrown vegetation, building walls, or any surfaces below them. This condition raises the electric potential of tangible objects around us and may result in death by electrocution, severe electrical burns, or fires ignited by arcing and heating of materials. The occurrence of such conditions also constitutes a loss of energy to the power companies as not all of the produced electrical power is delivered to their appointed loads. Power is lost on the way of delivery and dissipated through foreign objects which should not be in contact with the line. Conventional relaying schemes monitor short-circuit conditions where a significant amount of the energy supplied by the power company flows directly into the ground and never reaches its load. This condition is more critical for normal system operation than the one in this study. Diverse and effective solutions have already been found or this type of fault. The type of faulted condition in this study is the one that appears "invisible" to conventional fault detection methods and is caused by a leakage or small current that flows through surrounding objects that present high impedance in the current path to ground. These kinds of faults are hard to detect by monitoring equipment because their presence result only slight increases in load current; thus can be confused with a normal increase in load. In this paper a new technique is proposed to model, locate, and detect high-impedance faults. Patterns and characteristics in the line's current provide for recognition and are

investigated to detect such faults. The characteristics of the line's current are referred to as signatures pertaining to a HIF and are used to derive an algorithm to detect the occurrence of such.
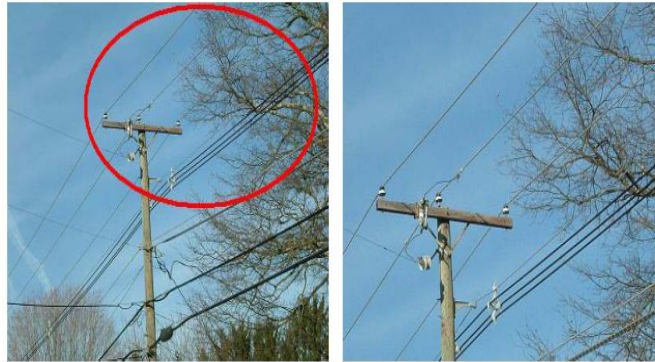

Figure. 1. Potential HIF Due to Tree-Limb Contact

High-impedance faults (HIFs) are defined as unwanted electrical contact between a bare energized conductor and a non-conducting foreign object. Non-conductors present high impedances to current flow due to their material, so a fault of this type will not appear to the protection equipment as an abnormal condition. Regardless of the circumstance of contact, a leakage current leaves the energized conductor and flows into the ground via tangible objects that are raised to a high potential posing a threat on human lives to say the least. Foreign objects, in the case of study, are naturally non-conductors but may conduct if the applied voltage is sufficient. These foreign objects present high electrical impedances allowing only small amounts of currents through them. The most common type of high-impedance faults are caused when contact with tree limbs, vegetation, concrete walls, and ground surfaces occur. The aforementioned objects happen to be very close to the distribution feeder's conductors and are eligible for unwanted contact at any time. An outdoor distribution feeder Conventional detection schemes monitor only low-impedance faults instantaneous and large increments of current due to a low-impedance path to ground (short-circuit). A HIF seems invisible to such detection methods because it presents only a small increment in line current and appears to be a normal load increment. energy conservation, and better electric service for consumers, a realistic model of a HIF is implemented and a method of detecting high-impedance faults is proposed. Conventional detection schemes "see" this problem as invisible, so even in its presence no alert or proactive action is ever taken. In this work, two types of HIFs will be modeled and studied. The first is caused when an energized conductor breaks and falls onto the ground. This leaves the fallen conductor on the floor energized at its full potential but detached from the rest of the network. The contacting

surface becomes a load to the broken phase end, and depending on the type of material, a variable amount of current may flow through it and into the ground. The current through such fault is small when the new path to ground presents high electrical impedance to current
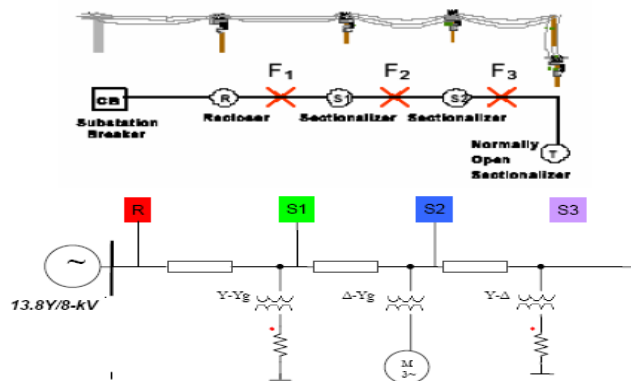

Figure 2. Distribution feeder showing substation,

In this study a HIF disturbances will be placed at F1, F2, and F3 respectively as line-to-ground fault. The captured harmonic information is used to test the proposed HIF detection and location algorithm. The action of either alerting or isolating the fault is beyond the scope of this work. It involves liability issues and further urban/rural information must be considered before taking action. For instance, if a HIF exists due to a downed conductor near a school where children are exposed to the energized conductor, the action should be proactive the line should be tripped. On the other hand, if the same HIF occurs out in valleys where no habitat exists, the line should continue to distribute electrical service to its appointed pre-fault-location loads

2. Voltage Transformers

Simplorer comes with a three-phase transformer model with appropriate coupling coefficient constants for its windings. The transformer model is linear and never saturates, as is also the case with real power transformers. Therefore, there was no need to derive a model for its non-linear core properties as is done for current transformers

2.1 High-Impedance Fault

High-impedance faults have "signature" characteristics in their transient and steady-state regimes that make them identifiable. These characteristics are listed in Table 9. To simulate a HIF, the model is taken from [10] and reproduced in Simplorer using two time-varying

resistances. The two variable resistances cause the phase current to present the characteristics

Table.3. Signature characteristics of HIFs

SIGNATURE	DESCRIPTION
Asymmetry	HIF current presents DC offset making it asymmetrical
Build-up	HIF current progressively increases until it reaches steady-state.
Shoulder	During build-up HIF current halts increase for a few cycles then continues
Non-linearity	HIF current not truly sinusoidal. Pronounced odd harmonics

Present shoulder, but some do so both the no-shoulder and shoulder-present cases are modeled to cover a wider variety of HIFs in looking for consistent patterns. To reproduce the HIF model in Simplorer®, two resistances $R1$ and $R2$ are placed in series as
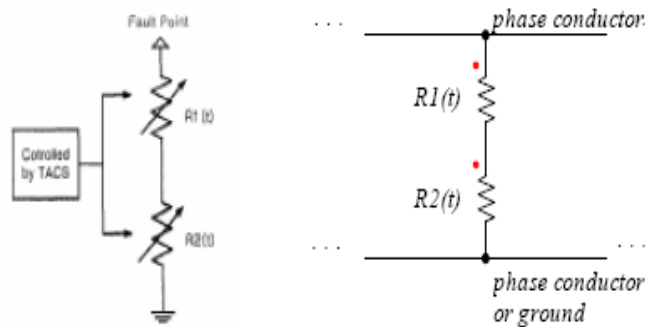

Figure.4. HIF model using two time-varying resistances

The second resistance $R2$ decays exponentially reaching the value of zero after ~0.4 seconds for the non-shoulder case, and ~0.5 seconds for the shoulder case. This characteristics is what produces build-up.
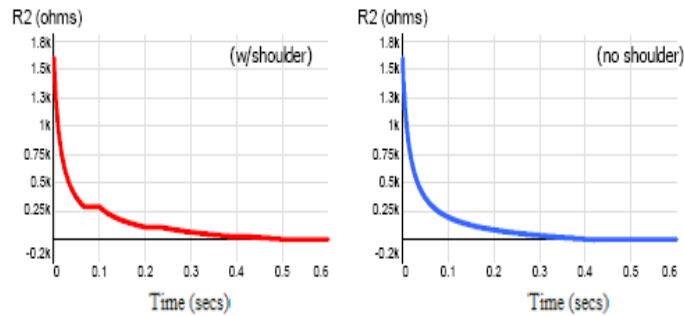
Figure.5. R2(t) value for shoulder (left) and nonshoulder (right) HIF cases.

Two curves for $R2$'s exponential decay are shown in Figure The leftmost presents a periodic flat slopes that cause the shoulder effect on the HIF current by maintaining the same value of resistance for small periods of time; this stops the current from increasing momentarily. The rightmost curve is the no-shoulder case and it causes a continuous exponential increase in HIF current. The equation for $R2(t)$ for the no-shoulder case is found by inspection from KEPCO's results in [10] as The loads were carefully chosen and modeled based on what is typical on a distribution feeder. The steady-state (motor unloaded) line current is about 50-A. This is rather low on a 20-mile distribution feeder, but the addition of more loads is not necessary because the proposed HIF

works regardless of the loading conditions (i.e. for 50 or 500A line current). Yet, in order to simulate more loads on the line, current sources (one per phase) are placed at end of the bus to pull current (~500A) through the feeder and source "fictitious" loads
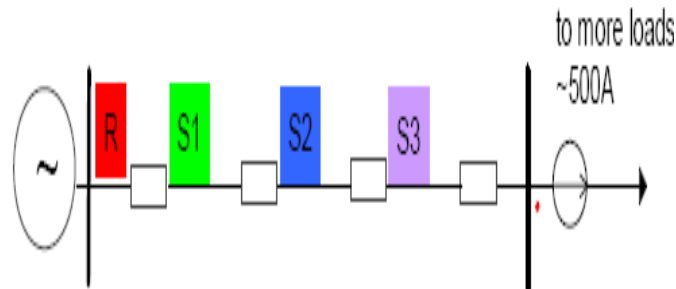

Figure.6. Current source mimics typical load demand

III. CURRENT TRANSFORMERS

In distribution feeders, current transformers (CTs) might reach momentary saturation due to large motor starting-currents, short-circuit conditions, burden faults, or an excess demand in one of their phases. The pronounced third-harmonic current, and its angle, in a saturated CT Closely related to third harmonic magnitude and angle in a HIF.

3.1 Impact of Saturated CTs in Distribution Feeders

Saturation in ferromagnetic cores occurs when the flux's density reaches its maximum and the core starts showing the magnetic characteristic of free-space. The impact of saturated ferrites in electrical networks is of interest in protection, power quality, and other areas of study to avoid misinterpretations in current readings and to avoid harmonic injection or sinking in the system. Several methods have been proposed to model the electrical behavior of a network in the presence of a saturated device during transients and in steady-state. Other works also model hysterisis loops with great precision but mainly to study inrush currents in transformers or accurate reclosure events [17] during transients. Other techniques exist where slopes and intercepts at various points of hysterisis loops are selected to calculate a model curve [18]. While also accurate, the need for many differential equations and ferromagnetic theory [17], [18] is not necessary when using the

proposed methods of modeling hysterisis loops. Linearizing and magnetic circuits have also been implemented to model hysterisis loops by using straight-line approximations; an inconvenience is that linearizing only models the characteristics of one ferrite at a time and is not adjustable unless the data is re-tabulated. The study of HIF required a simple method for modeling hysterisis loops that did not use differential equations or ferromagnetic theory, but at the same time delivered an accurate model of the saturated condition.
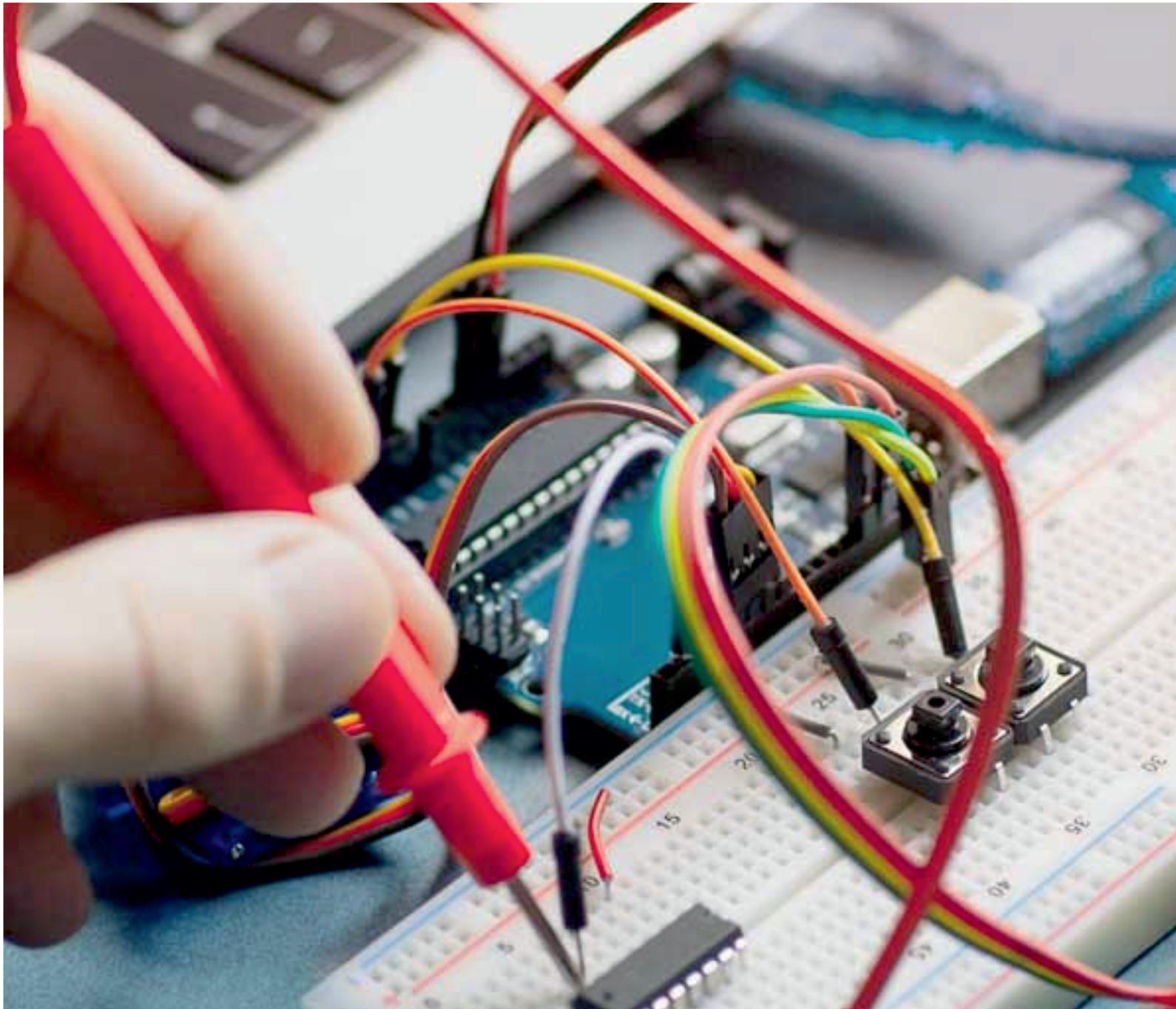
IV. CONCLUSIONS

Most high-impedance faults can be detected using harmonic-current phase-angle analysis and localized by using recloser-sectionalizer technology. In simlink model detectors such as sectionalizers, various typical HIF patterns must be programmed to the module in the form of detection flags. Sectionalizers will constantly be looking for these typical patterns of a HIF as provided in this work. If the current patterns meet the detection criteria, adjusted sectionalizers will communicate with each other in trying to locate the fault. The work assumes phase since they account for the greater majority of HIFs. Due to the strong harmonic-angle dependence, transient conditions in distribution feeders can cause false readings. These are overseen by the detection discriminates against multi-phase and short-duration effects. For instance, capacitor switching would be of very short-duration (1-3cycles) and would happen in all three-phases. High impedance faults are normally single-phase and are sustained.

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