INTELLIGENT FAULT LOCATION FOR LOW VOLTAGE DISTRIBUTION NETWORKS

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ABSTRACT

A fault location technology for low voltage distribution networks (LVDN) is described. Technical details and performance of the intelligent fault location (IFL) system and its usefulness in inaccessible cable situations are presented. The intelligence incorporated into the new system uses adaptive signal processing methods on TDR based signal returns to determine the location of a specific line fault. Results of the on-line IFL system operating automatically on real single, two or three phase networks are included. The results indicate that the IFL has the ability to see through single phase branches from the network. The novel technology allows faults on LVDN at ranges of up to 1000m to be identified. The results from field trials are presented to demonstrate the significant performance achieved with this system.

INTRODUCTION

The vulnerability of electricity distribution networks has been highlighted by a number of high profile incidents. For example, the catastrophic failure of the North American East Coast Transmission network in 2003 highlighted the fact that electricity transmission systems in developed countries are ageing. Deterioration in the insulation qualities of cables and cable-joints means that elderly underground LV cable installations are increasingly likely to develop faults which can cut off the supply to large areas causing misery for potentially thousands of people.

Faults fall under two categories: permanent faults (where the electricity supply remains off until the fault is located), and transient faults (where there is intermittent loss of power). Pinpointing the exact locations of either type of cable fault is currently hit and miss, as many LV (low voltage) cable systems have a complex system of multiple T-joints which confuse existing cable fault detection technology, resulting in lengthy downtime and numerous costly highway excavations. Costs to the Power Utility include a regulatory cost for each hour the electricity supply is lost, excavation cost and labour cost as well as deterioration in the brand image of the company. We consider permanent Underground Low Voltage Distribution Networks (ULVDN) faults in this paper.

Time Domain Reflectometry (TDR) is one of the most common methods used for locating faults on Underground cables and transmission lines [1-6]. Although TDR based [7-8] methods have proven useful in high voltage networks they have proved less successful in ULVDNs. This is due to multiple 3-phase and single-phase (service cable) tee joints in the ULVDN. Due to the multiple tees, the TDR recorded signals are much more complicated than those obtained from high and medium voltage underground cables, and overhead transmission lines [9].

The system developed in [1] is TDR based and requires experienced engineers to interpret the waveforms. The system described in [2] uses the TDR principle to locate the fault automatically. This method can locate faults for cable network that consists of 3-phase tees, but did not consider cable network with single-phase tees and can only be applied to cable lines of voltage 6.6kV to 33kV. The fault location technique described in [3] uses wavelet transform to analyse the power system fault transients in TDR signals. It was only applied to 345kV transmission lines without tees. The system described in [4] uses expert knowledge to simplify the fault location procedures. However, it still requires some user inputs and the technique was demonstrated for high voltage underground cable without tees. The fault locating system described in [8] automates the fault locating process. It requires three stages to locate faults, and was only demonstrated for 15kV distribution cables network without tees.

Some of the key issues in ULVDN fault analyses include:

- TDR recorded signals are not easy to interpret due to reflections from the many tee connections in the network
- Single-phase tees may produce reflections similar to short circuits, therefore it is difficult to distinguish between single-phase tee and short circuit fault from the reflections recorded
- When fault location is carried out on live lines, not all the access points for fault recordings are isolated from the bus bar. If the access point is not isolated from the bus bar then it is not possible to record good healthy phase reflected signals. This is because the pulse launched into the cable travels into other feeders as well. Therefore, the recordings that can

only be made are related to the faulty phase. To record a healthy phase reflected signal, additional fuses need to be taken off which will lead to power outages to customers.

This paper describes the characteristics and performance of an automatic system (hereafter denoted by IFL) based on intelligent processing of the TDR signals for locating faults on ULDVN. The IFL technology locates faults by differentiating all types of tees and faults. The performance of the IFL technology was evaluated using field data that were obtained from real ULVDNs.

ULVDN DATA RECORDING

Recording the number of reflected signals in a faulted 3-phase live ULVDN cable without the need for blocking inductors (to avoid the pulse travelling into the feeder) can be grouped into three categories namely: (i) one fuse out (ii) two fuses out (iii) three fuses out.

Removal of one fuse (either blown or taken out) allows three reflected signals to be recorded from an access point. For example, if the Red phase fuse is blown or taken out then the reflected signals that can be recorded must be associated with Red phase. Therefore, Red-Neutral (RN), Red-Blue (RB), and Red-Yellow (RY) reflected signals can be recorded if Red fuse is blown. Another fuse needs to be taken off if other reflected signals need to be recorded. This will lead to further customer power outage. Removal of two fuses (either blown or taken out) allows five reflected signals to be recorded from an access point. For this case if the Red and Blue fuses are blown then RN, BN, RB, and BY reflected signals can be recorded without any further customer power outage.

All six reflected signals (RN, BN, YN, RB, YB) can be recorded if all three phases are blown or taken out from the access point. On 2-phase ULVDNs with 1 fuse out 2 useful recordings would be possible. Both fuses out would result in 3 useful recorded signals. Obviously there would be one signal recorded for a single phase network with a blown fuse.

IFL FOR ULVDN PERMANENT FAULTS

The key characteristic of the approach used in the IFL-1000 instrument [10], pictured in Fig 1, is the way the reflected signals are compared to each other. The flowchart for the IFL TDR based fault location system is shown in Fig.2.
Initially, possible reflected signals are recorded using the IFL-1000 based TDR instrument. Sampling frequencies between 125M to 500M samples per second may be selected with a variable pulse width to facilitate a far range, mid range and a near range acquisition mode.

Figure 1: IFL-1000 Intelligent Fault Locator [10]

The unit uses a Texas Instruments DSP for efficient signal acquisition and subsequent processing. All phase signals (live and not live) are connected to the IFL device. In the case of a 2 phase ULDVN the spare connection is tied to one of the others. In the case of a single phase network all three phase connectors on the IFL are tied together. Appropriate numbers of phase-to-phase and phase-to-neutral signals are automatically recorded and input to the signal conditioner and pre-processing unit.

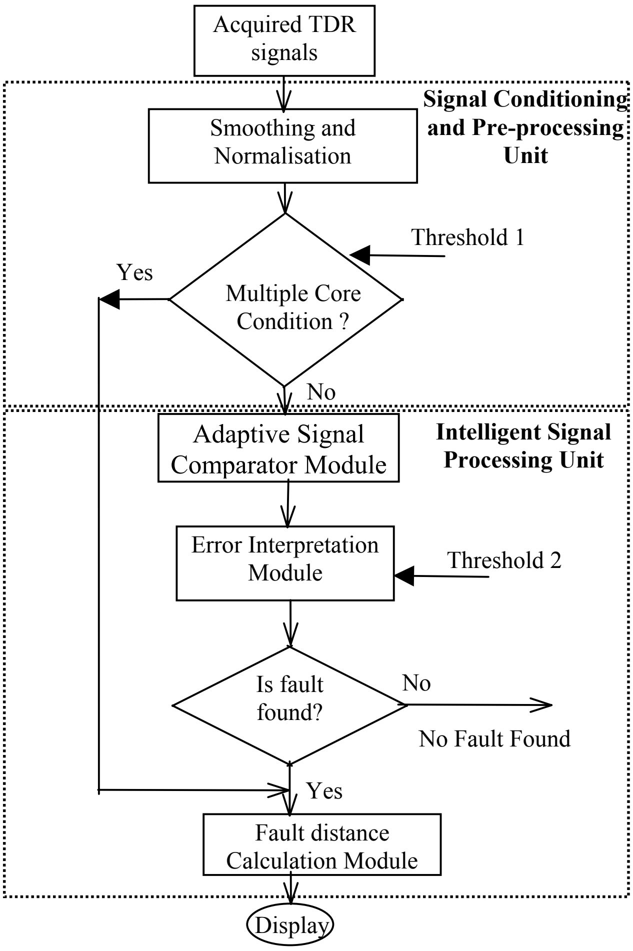

Figure 2: Intelligent Fault Locator Flow Diagram

The set of normalized phase-to-phase and phase-to-neutral returns are interrogated to check for potential multiple-phase tee offs or multiple phase faults. The normalized returns are fed to the distance location module on the detection of a multiple phase tee off or multiple phase fault otherwise they are forwarded to the intelligent signal processing unit.

The intelligent signal processing unit comprises three components: (i) adaptive signal comparator and error generator module (ii) fault interpretation module and (iii) distance locator module. In the adaptive signal comparator module adaptive filters are used on all reflected signals in pairs and all possible combinations to produce a number of adaptive error signals. The adaptive filter output (error signal) will give more accurate departures between the pair of reflected signals and not simply the amplitude difference as in the conventional compare and contrast (C&C) approach. In the second component the resulting adaptive error signals are input to the fault interpretation module in order to localise the significant key departures. The intelligent method uses a combination of error amplitude and time of occurrence in order to select the possible fault location. In the final component (the distance locator module) the fault distance is calculated using the raw error signal by finding the position where signal departure commenced.

The IFL method addresses the single-phase tee problem. It does not require an experienced engineer to interpret the results. It operates on available TDR data to locate faults, and can be used on live line.

RESULTS FROM REAL ULVDNS

CASE STUDY 1:

The relative performance of the IFL and the conventional compare & contrast (C&C) TDR methods is evaluated using

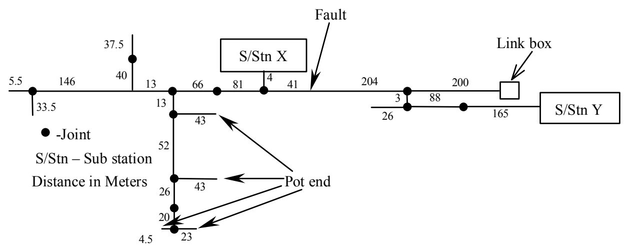

Figure 3 Real ULVDN Cable Map

field data that were obtained from real ULVDNs.

The first set of reflected signals Red-Yellow (RY), Red-Blue (RB) that is shown in Fig.4 was recorded from the real cable network as illustrated in Fig.3. The reflected signals were recorded from sub station X. The fault was 45m from the sub station X and it was RY short circuit fault. The two reflected signals have a negative reflection at 8m from the sub station X. This is due to the 3-phase tee joint. The RY reflected signal has another negative reflection at 45m due to the short circuit fault. The RB reflected signal goes slightly negative at 45m. This is due to the effect of the short circuit between Red and Yellow phase.

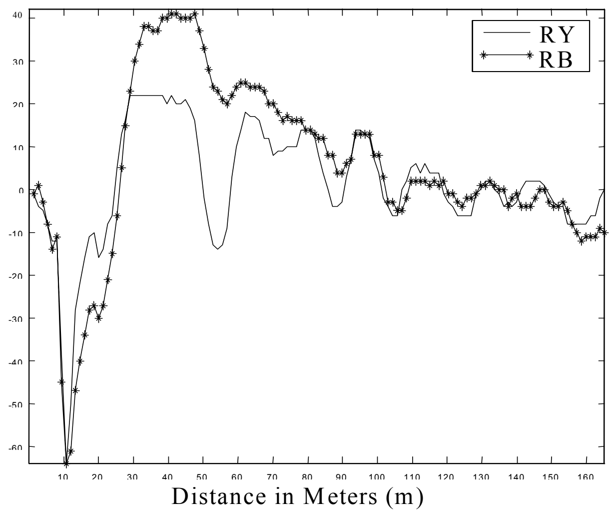

Fig.4. Reflected Phase-two-Phase Signals

The adaptive error and C&C error signal are shown in Fig 5.The former has departures at approximately 10m and just before 40m and requires user interpretation to eliminate the 10m departure as a possible fault location.

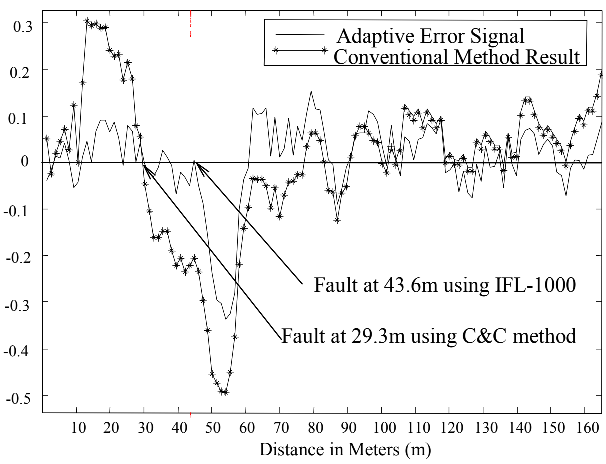

Fig.5 IFL-1000 raw error signal and the conventional method's difference signal

The fault distance is calculated using the raw error signal by estimating where the signal departure started as shown in Fig.5. It was found at 43.6m using the IFL and 29.3m using the C&C method resulting in respective errors of 1.4m and 16.7 m.

CASE STUDY 2:

The second case study comprises a 2-phase network that had multiple single phase tee offs between access point and fault. The actual fault was located approximately 105 meters from the access point. Fig 9 shows the normalised Phase-to-Neutral signals recorded with the IFL-1000 in near mode. The IFL-1000 automatically locates the Phase-to-Neutral fault at 107.91m as illustrated in Fig 10.

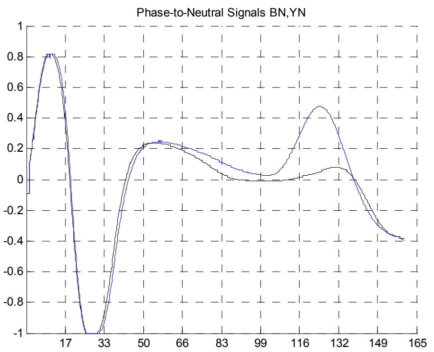

Figure 9 Phase-to-Neutral Signals

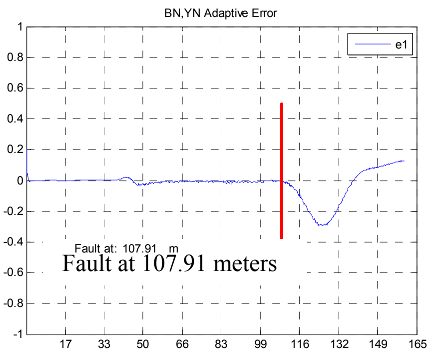

Figure 10 Fault location automatically computed by the IFL-1000 instrument

CONCLUSIONS

In this paper a system for locating permanent faults in underground low voltage distribution networks was presented. The IFL-1000 instrument uses a traditional TDR approach in combination with an intelligent signal-processing unit. This location is automatic by using intelligent processing of the acquired TDR signals. It can be used on 1-phase, 2-phase or 3-phase low voltage distribution networks. The location can take place on live lines thus minimizing disruption caused to customers. The IFL-1000 instrument allows users to locate ULVDN cable faults without user interpretation. The IFL-1000 can 'see through' multiple single phase and 3-phase tee offs. The results of the field trials to date are very encouraging.

ACKNOWLEDGMENTS

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