RELIABLE DETECTION OF DOWNED AND BROKEN CONDUCTORS

Eilert BJERKAN
NORTROLL AS – Norway
ebjerkan@nortroll.no

Hans Kristian HØIDALEN
NTNU – Norway
Hans.Hoidalen@elkraft.ntnu.no

Johan G. HERNES
NTE NETT AS - Norway
johan.hernes@nte.no

ABSTRACT

A method to detect and locate high impedance faults generated by downed conductors is presented. These faults usually represent very low fault currents and are usually not detectable by the feeder protection. Sensitive feeder protection systems exist but are usually troubled with faulty operation during normal system changes such as switching etc. The proposed method is based on distributed voltage measurements performed at MV/LV stations/transformers throughout the distribution network, or at least at its extremities and will work for both insulated as well as bare conductors. The method detects the fault by activating all units downstream of the fault. The SCADA-operator (or the SCADA system itself) locate the fault by searching for the last inactive and the first active unit and then perform necessary sectionalizing to minimize penalty costs before instructing the line crew.

INTRODUCTION

Detecting and locating high impedance faults (HIF) in distribution networks has been a major challenge for the power electric community for decades. HIFs are very difficult to detect by the use of traditional overcurrent relays due to the small magnitude of the fault current.

A HIF is usually characterized by an arcing fault due to broken conductors or contact with high resistive objects such as trees, vehicles, concrete, rocks etc.

The situation becomes even worse if a downed conductor touches ground on the load side (back-fed earthfault as illustrated in Figure 1) or does not touch ground at all (a broken loop), since these faults rarely trips traditional relays. Feeders containing distributed generation (DG) aggravate the situation since an automatic DG disconnection is not ensured during such faults and then fault detection and location becomes difficult.

The most serious type of HIF is a downed conductor without automatic disconnection since risk of injuries due to fire or electric shock is present with an energized conductor on the ground.

Santander et al. [1] states the fact that currently used protection equipment fail to detect 30-50% of downed conductor faults which is similar to fault statistics in Norway [2]. Dealing with downed conductors does not only involve some technical issues but also several complex legal, economic and operational matters as well [3].

Many studies have been performed and solutions provided where most of them are implemented as feeder protection and are current-based (either harmonics or transients) as reviewed by Li and Redfern [4]. Signal processing and neural networks are frequently used in these applications to increase sensitivity, but these sensitive methods usually have a low reliability due to faulty operation during normal changes in the network such as switching operations, arcing loads etc.

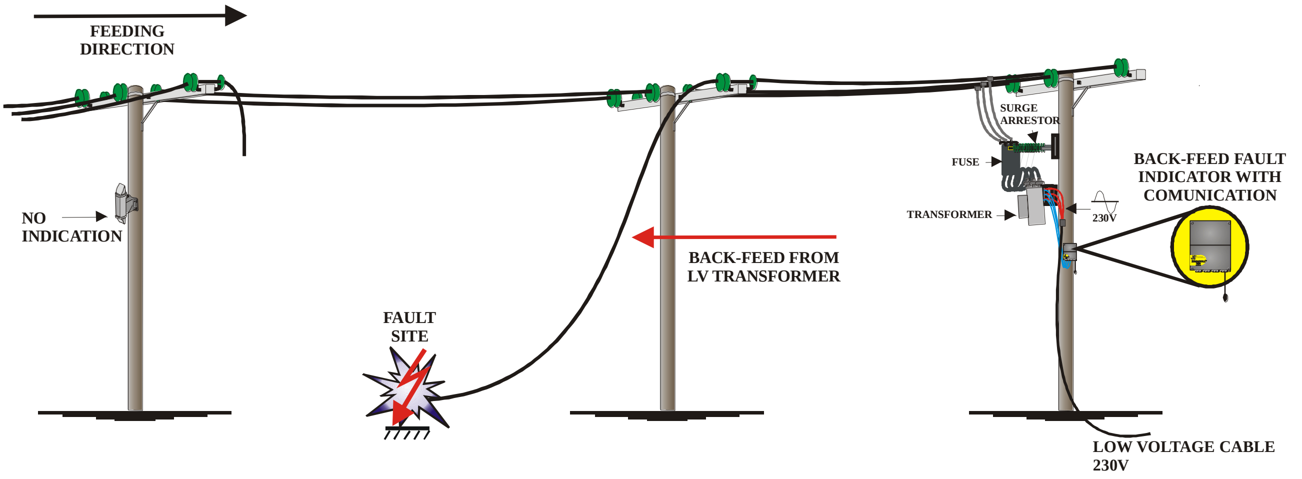

Figure 1: Backfed earthfault due to a load-side downed conductor not detected by the feeder protection

Another limitation for substation-based systems is the lack of selectivity since the location along the feeder is unknown and line patrolling along the whole feeder is necessary to identify and locate a possible problem. Also a low fault current would be a major limitation for this kind of method since it depends on the resistance of the fault current path. In dry and high resistive environments the fault current may in fact be zero [1] (dry asphalt or sand) and then the detection would not be possible.

VOLTAGE BASED METHOD

Several publications have proposed to use distributed voltage-measurements as an alternative to substation-based systems. This seems to be easier since the change in voltages downstream of a downed and broken conductor would mainly be independent of the fault resistance. In the US this is easily accomplished since single phase circuits are extensively used [5] and a simple voltage loss detector may be used. In Europe and many other places 3-phase is usually used for MV distribution. This complicates the fault detection and some methods use the degree of change in positive and zero sequence voltage [1], others use the negative sequence voltage. Sensors below the power line [6] have also been suggested to sense on the resulting electrical field below the powerline, but these units will not be able to differ between regular earthfaults and downed conductors in networks with isolated or compensated MV neutral.

For an effective location of the downed conductor, these units must at least be installed at all extremities of the network and preferably also at important nodes along the feeders. When using the MV/LV stations/transformers for measurements, no expensive potential transformers would be needed if the transformer model is handled appropriately.

All sensors downstream of the fault site would send an alarm to the SCADA-system which in turn dynamically could show the line section containing the fault (see fig.2) and make an advisory operation list to the operator to minimize penalty costs by re-sectionalizing the network which then allocates his line crew to the correct position in the network.

FAULT DETECTION

The fault detectors measure the line voltages at the LV terminals of distribution transformers throughout the network. The stationary changes in amplitude and phase of these voltages are used for detection (either by using symm. components or dir. comparison). Since different connection groups may be used, the unit must be able to recognize the different signals produced by the different connection groups, the most important ones being Dyn, Yyn, Yzn.

Another important aspect to consider regarding connection groups is the fact that there may be several different connection groups present downstream of the fault. This leads to a special back-feed configuration where the broken phase resembles a “closer-to-normal” condition. This must be accommodated in the detection routines. Also the routines must accommodate for other fault-types in both the MV and LV networks to avoid false operation.

All of this leads to a special routine that evaluates the duration, amplitude and phase of the individual line voltages measured. The secondary load at the transformers is important and tests are performed to fine tune the routines to handle everything between full and no load for all connection groups.

Another advantage of this method compared to the more advanced substation-based methods are the ability to detect broken loops (no connection to earth) and blown HV-fuses. These are faults that up to now have usually been reported by displeased customers.

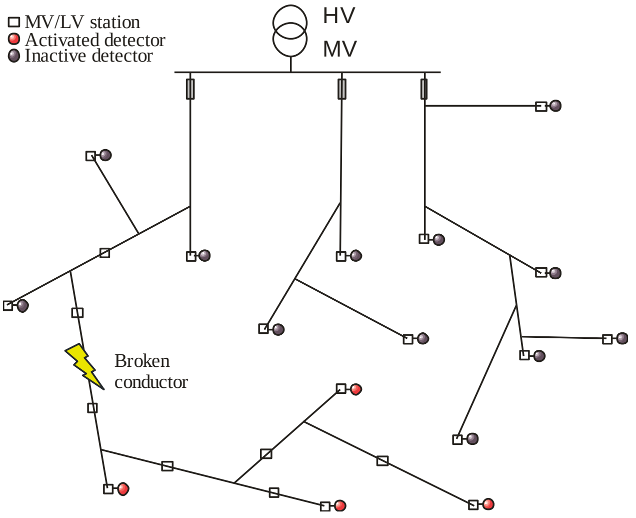

Figure 2: Topology of detectors in a radial distribution system

FAULT LOCATION

In order to locate and isolate the fault-site efficiently, the SCADA system can utilize an algorithm that compares activated sensors with topological information (see Figure 2) of the network in addition to information on the status of switch positions in opened ring networks etc. The result is an advisory list to the operator on how to isolate the fault in the most efficient manner compared to penalty costs if there are several options (directions of feeding). This of course requires a link between the SCADA and the network information system in order to estimate the solution that minimizes penalty costs.

For redundancy and high degree of accuracy it is recommended that not only distribution transformers at the feeder's extremities are supplied with such fault locators but also other transformers along the main sections of the feeders.

Signalling from the fault detector to the substation or control centre could be done by many different means such as radio communication, power line communication (PLC), GSM/GPRS, fibre, leased lines and so on. It is essential that the communication option of highest possible reliability is used to ensure correct location of the faults. In this sense PLC [6] from downstream of a broken conductor would not be beneficial.

FIELD TEST

Several field tests have been performed in order to verify the basic principles of detection. The one reported in this paper was performed at the local utility (NTE Nett). The network subjected to the field tests has three feeders where one has the possibility of supplying all customers from another substation (see Figure 3). This enabled the possibility of having the feeder with its protection exclusively for the test setup (no customer interruptions). The network represents typical networks in rural areas of Norway with a 66/22kV main transformer, compensated neutral and 3-4 feeders.

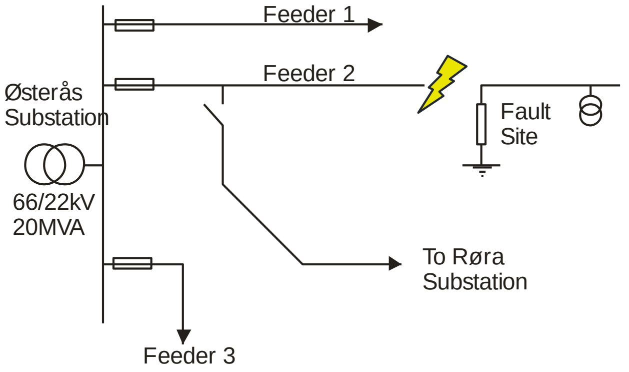

Figure 3: Field test, network layout

Several different configurations were tested varying the load and fault resistance in order identify weaknesses in the detection routines. The distribution transformer was a Yyn 150kVA 22/0.22kV. Secondary three-phase loading was either 15.7kW or no load. Fault resistance tested was either 0 or 3 kΩ. The broken conductor was put to ground on the load side (back-fed fault) as shown in Figure 4. Also some faults without grounding the broken conductor were tested successfully in order to simulate a blown HV fuse or a broken loop.

One interesting result during these tests was the lack of influence of the fault resistance regarding the operation of the feeder protection. 10 different tests were performed and the feeder protection did not detect any of these faults, but the voltage imbalance detector correctly detected all the faults. It was obvious that the loading of the transformer in addition to its magnetizing impedance is determining for the impedance seen by the fault current flowing through the distribution transformer on the MV side.

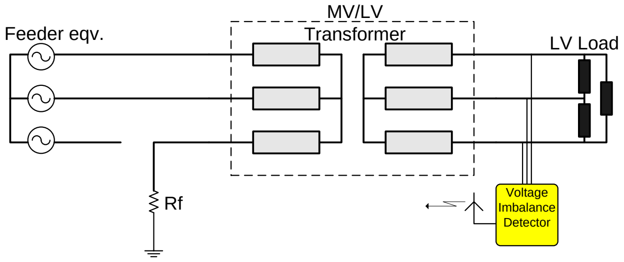

Figure 4: Back-feed through distribution transformer

The resistance seen from the primary side due to the load is determined by:

$$R = \frac{U^2}{P} = \frac{(22kV)^2}{15.7kW} = 30.8k\Omega \qquad \text{(Eq. 1)}$$

Since the fault current is supplied by two healthy phases the equivalent resistance seen by the fault current will be:

$$1.5 \cdot R = 46.2k\Omega \qquad \text{(Eq. 2)}$$

The measured and calculated fault current (at the fault-site) was 0.1A and 0.15A respectively. Several transformers downstream with a higher degree of loading will certainly reduce the resistance seen by the fault current, and the actual fault resistance between the downed wire and ground becomes more important. Still the problem persists if the ground is high resistive such as snow, asphalt, concrete, dry sand, rocks and so on.

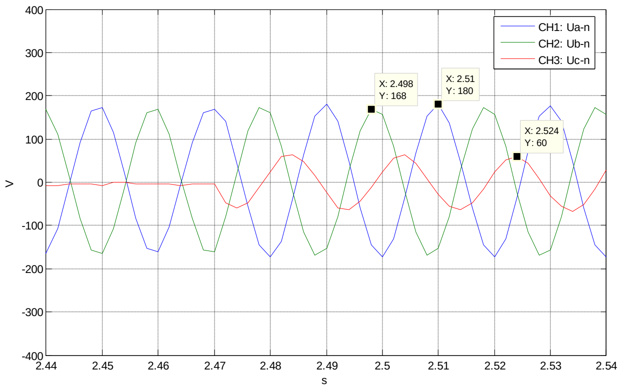

Figure 5: Measured secondary voltages during transition from broken to downed conductor

Figure 5 shows the measured secondary phase to ground voltages at the instant where the broken conductor falls to ground and becomes grounded. Phase and magnitude information stands out and a reliable detection of downed conductor is possible. In this case no arcing is involved.

DISCUSSIONS

The voltage imbalance method is superior to any other substation-based method (that relies on current measurements). The disadvantage is the need for a reliable communication from a high number of field devices. If a variety of information could be enabled by this communication, it would be easier for utilities to accept such a solution. The device described and tested in this paper has such functionality implemented (earthfault-detection in the LV network, status of surge protectors, transformer temperature/pressure, signalling from other fault indicators along the feeder, MV/LV load current monitoring, power quality monitoring etc.)

Another topic for units used for detection of downed and broken conductors would be distributed generation (DG) since a DG-unit downstream of the fault could be capable of restoring the voltage on the faulty phase. An automatic disconnection of the DG-unit is not necessarily true. A complementary device that will be used together with the voltage imbalance detector is a MV phase mounted wireless current monitor. This unit evaluates current imbalance throughout the feeder in order to identify a line break if DG is present in the network, but increase the total cost of the protection system.

CONCLUSIONS

The method for detecting downed and broken conductors described in this paper holds several advantages compared to substation-based methods, since the signals are easier to discriminate from other fault-generated signals. The method also detects fault with infinite fault resistance (no ground connection such as broken loops) and blown HV fuses. Another advantage is that the fault may be located more accurately with distributed measurements (depending on the number of devices installed along the feeder) since the whole feeder must be patrolled when using a substation-based method. Distance calculations are only applicable for low impedance faults.

The critical part for this method is the communication to the SCADA system/substation and the interpretation performed by the SCADA operator. If this is handled systematically, downed and broken conductors can be detected and located with a high degree of reliability.

The unit may also include other functions and by measuring on the LV terminals of distribution transformers, the unit becomes cost efficient for utilities experiencing downed conductor faults from time to time.

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