

A NEW AND INNOVATIVE WAY OF DETECTING RESTRIKING EARTH FAULTS IN THE DIGITAL AGE

After years of intensive research and field testing, ABB is now introducing the reliable digital alternative, which takes the detection of restriking earth-faults into next level. From now on there is no need for an additional and separate analogue transient relay resulting in reduced costs and time for installation and commissioning. Both network owners and operators will benefit - as the overall reliability of the protection will be increased.

INTRODUCTION

Restriking earth fault is a special type of fault that is encountered especially in compensated networks with underground cables. It is characterized by repetitious of short duration self-extinguishing faults as illustrated in **Fig. 1**. This kind of fault tends to be difficult for conventional directional earth fault protection relays to detect due to highly irregular wave shape of residual current. Whereas residual overvoltage relays used typically as a substation back-up protection have better chances for fault detection because of more steady behaviour of residual voltage. Due to this fact restriking earth faults can often cause non-selective tripping of the substation back-up protection and eventually an outage with substantial costs to unnecessary wide area.

The above problem can, however, be solved by developing more sophisticated protection methods. Traditionally the detection of restriking earth faults has been based on the polarity comparison of initial fault transients utilizing analogue measurements and

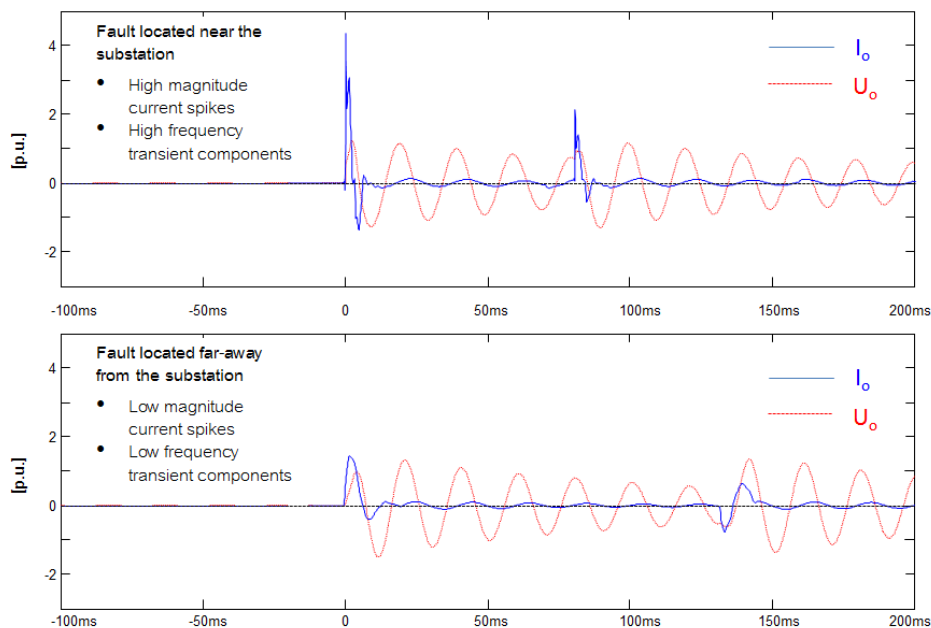


Fig. 1. Principle waveforms of I_o and U_o during an restriking earth-fault

separate hardware modules as reliable integrated digital alternative has not been available, until today.

NEW CHALLENGES...

Medium voltage networks are rapidly being developed towards self-healing smart grids. This is achieved by increased degree of automation with modern communication technology and by replacing the weather-vulnerable over-headlines with underground cables. Extensive cabling changes the electrical parameters of the network and brings also completely new challenges for earth-fault protection. In many cases the distributed compensation coils are installed along the feeders to compensate the highly increased earth-fault current. As a consequence of long cable feeders and additional distributed compensation coils the total damping of the network is significantly increased. This decreases the magnitudes and transient frequencies of the residual quantities, especially when faults are located far away from the substation. This is illustrated in **Fig. 1**, where the effect on fault location can be clearly seen in the quantities

measured by earth-fault protection during an actual trial earth-fault. The low magnitude and low frequency transients lead to decreased sensitivity of traditional transient based restriking earth-fault protection and necessities to validate its operation. It is also known that transient based methods are prone to maloperation when initial fault transients are superimposed by other high frequency components such as switching transients during switch-on-to-fault situation or during an unsuccessful auto-reclosing sequence. These facts bring the need to re-evaluate the principles used in transient and restriking earth-fault protection used today.

...REQUIRE NEW SOLUTIONS

After years of intensive research and field testing, ABB is now introducing the reliable digital alternative, which takes the detection of restriking earth-faults into next level. The patented algorithm utilizes the latest developments in digital signal processing including multi-frequency neutral admittance measurement and sophisticated filtering techniques. The principal

functional diagram of the novel algorithm, function block INTRPTEF, is illustrated in Fig. 2.

The first fundamental novelty of the algorithm is the utilization of multi-frequency neutral admittance measurement. The main advantage of monitoring the ratio of I_o and U_o , i.e. the neutral admittance, is that ideally the result is not affected by the fault resistance in the fault spot. This is due to the fact as both the I_o and U_o are decreased with increasing fault resistance value, their ratio i.e. the neutral admittance, remains constant. The algorithm utilizes in addition to the fundamental frequency component, automatically also the harmonic components, when their magnitudes are high enough for reliable measurement. Harmonics have very advantageous properties from earth-fault protection perspective, especially in case of compensated networks. This comes from the fact that for the higher frequencies the compensation coil appears as very high impedance. This simplifies the directional determination of an earth-fault as it can be based solely on the sign of the imaginary part of the operate quantity phasor. The utilization of harmonics makes the protection algorithm very robust and reliable in case the measured signals are distorted or include high frequency components as in case of a restriking earth-fault.

Another novelty of the algorithm is the directional element, where the discrete directional admittance phasors are replaced by the accumulated values of the same quantities during the fault. This concept of Cumulative Phasor Summing (or CPS) is illustrated in Fig. 3. CPS is the result of adding

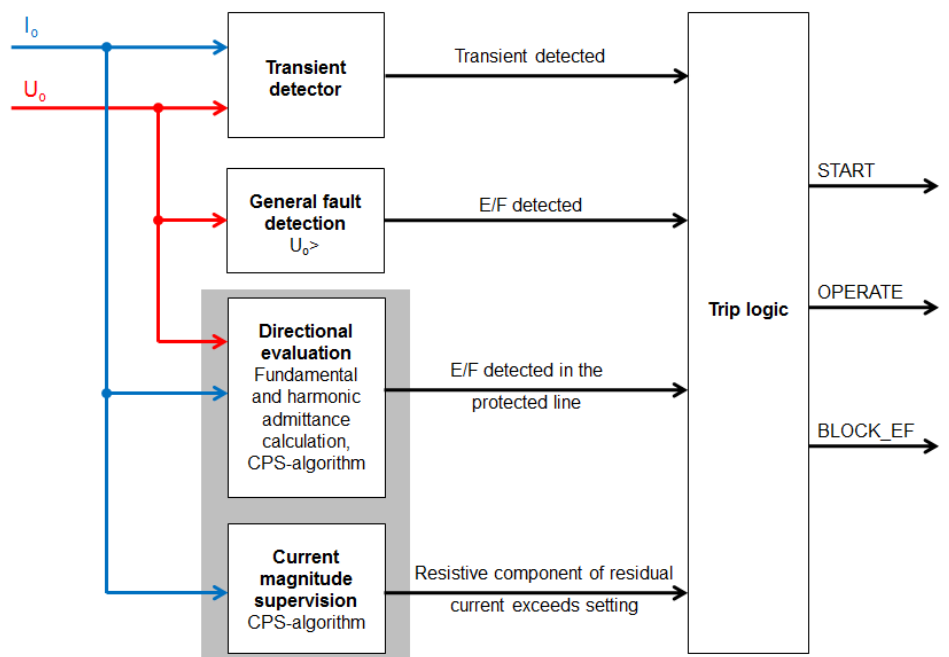


Fig. 2. Principal block diagram of novel restriking earth-fault (E/F) protection

values of the measured complex DFT-phasors together in phasor format starting at fault initiation. The directional phasor calculated by the CPS technique gives a very distinct and stable indication of the fault direction as the accumulated fault phasor points towards the direction of the highest energy flow i.e. in the fault direction. The fault direction becomes even clearer if harmonic components are present, as then the directional phasors in the faulty and healthy feeders point into fully opposite directions, as in case of an unearthed network, regardless of the actual compensation degree of the network.

Further advantageous feature of

the CPS technique is the ability to give a meaningful amplitude estimation of the resistive part of residual current also in case of transient or intermittent faults. This is achieved by dividing two accumulated phasor quantities (fundamental frequency residual current I_o and residual voltage U_o). Their quotient, the admittance, converges to the result, which (after conversion) represents the resistive current corresponding to the parallel resistor and the losses of the network. This current magnitude is directly related to the basic network data, which allows easy setting value determination. Further benefit is that this current estimation is not affected by fault resistance value due to

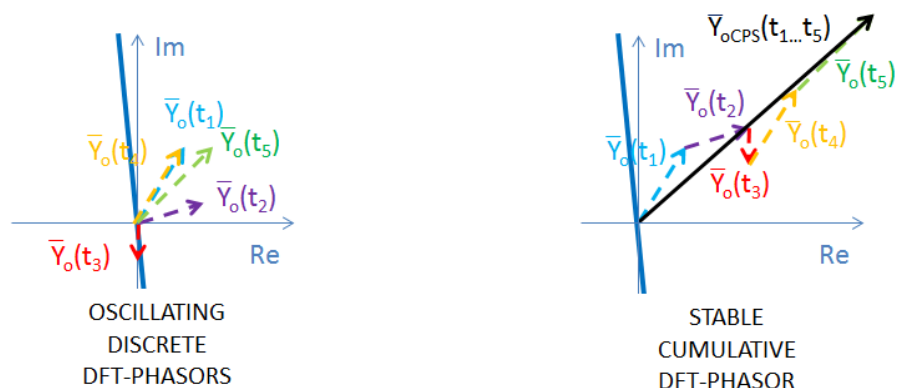


Fig. 3. Principle of Cumulative Phasor summing, CPS.

admittance based measurement method.

The novel algorithm provides a highly robust and selective identification of restriking and transient earth faults. The direction of fault can be monitored both in the faulty and the healthy feeders, which can be utilized to speed-up the actual fault location procedure. Thanks to the novel algorithm the sensitivity of transient detector can be greatly increased without sacrificing the reliability of protection. The sensitivity is then adequate for detecting even the lowest current spikes during a restriking earth-fault which could exist in today's extensive cable networks. Further advantage of the novel algorithm is the low demand for transient frequencies present in the fault signals, which makes also the secondary testing of this function much easier.

TWO OPERATION MODES

Depending on the set Operation mode, INTRPTEF function has two independent modes for detecting earth faults. The "Transient EF" mode is intended to detect all kinds of earth faults with adequate initial transients. The "Intermittent EF" mode is dedicated for detecting restriking earth faults in cable networks. The required number of detected transients to allow operation is given with setting Peak counter limit. Examples of both operation modes are given in Fig. 4 and Fig. 5. The sensitivity of the transient detection is adjusted with the Min operate current setting. The measured current needs to be higher than the set value to allow the transient detection. This setting should be set based on the value of the parallel resistor of the coil, with security margin. For example, if the resistive current of the parallel

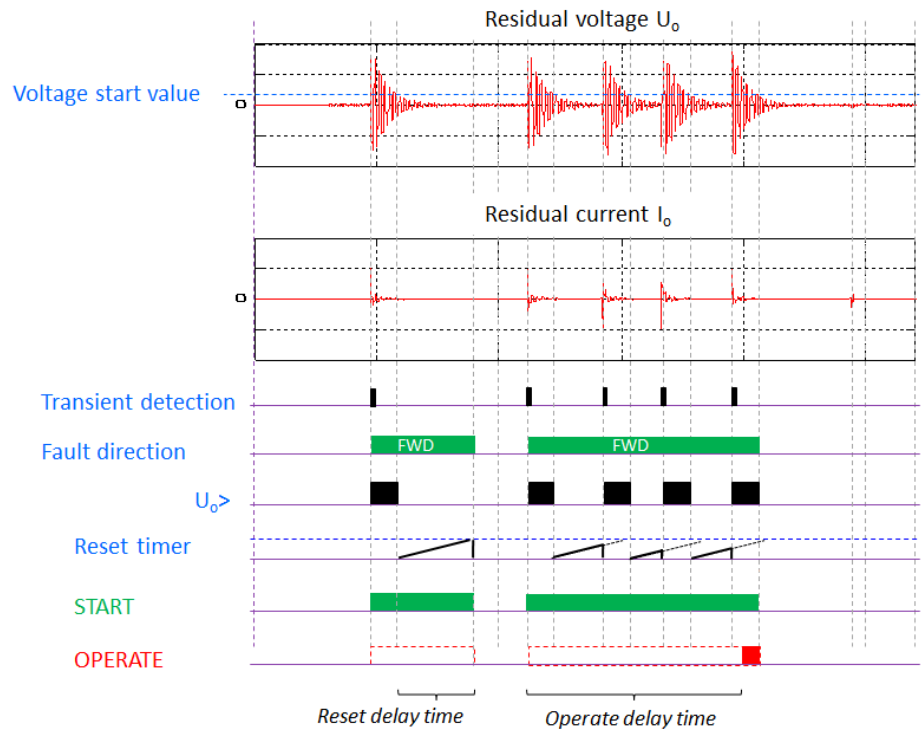


Fig. 4 Example of INTRPTEF operation in "Transient EF" mode in the faulty feeder.

resistor is 10 A, then a value lower than $0.7 \cdot 10A = 7A$ could be used.

It should be noted that in order to satisfy the requirements for sensitivity, traditional earth fault

protection should always be used in parallel with the INTRPTEF function. In case the earth-fault is detected outside the set operate direction, then the BLOCK_EF signal is given at time of fault transient

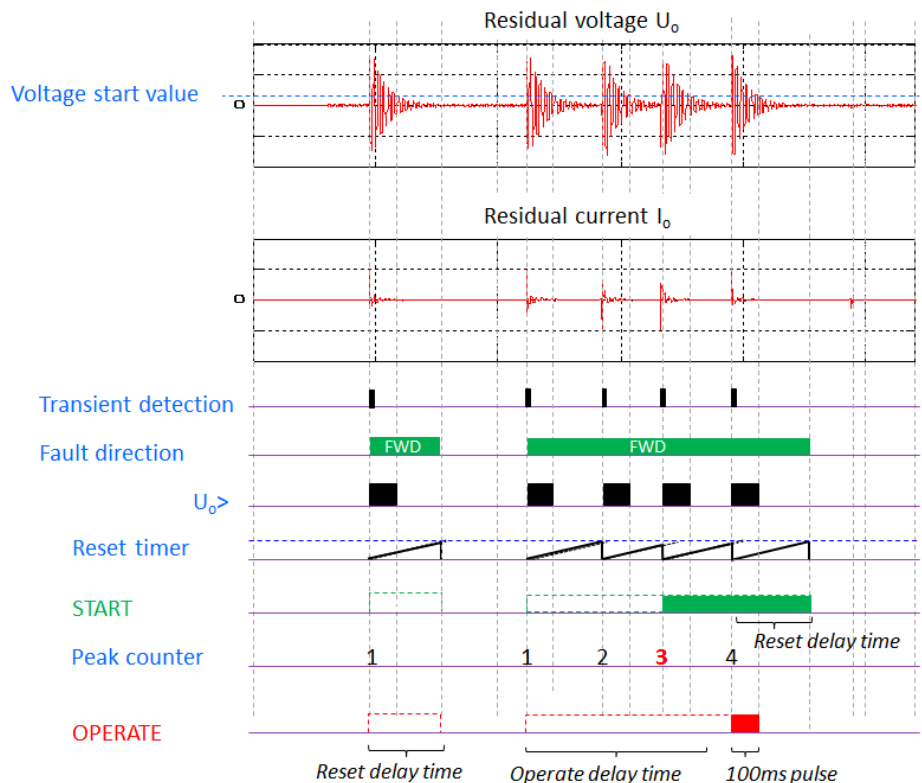


Fig. 5 Example of INTRPTEF operation in "Intermittent EF" mode in the faulty feeder, Peak counter limit = 3.

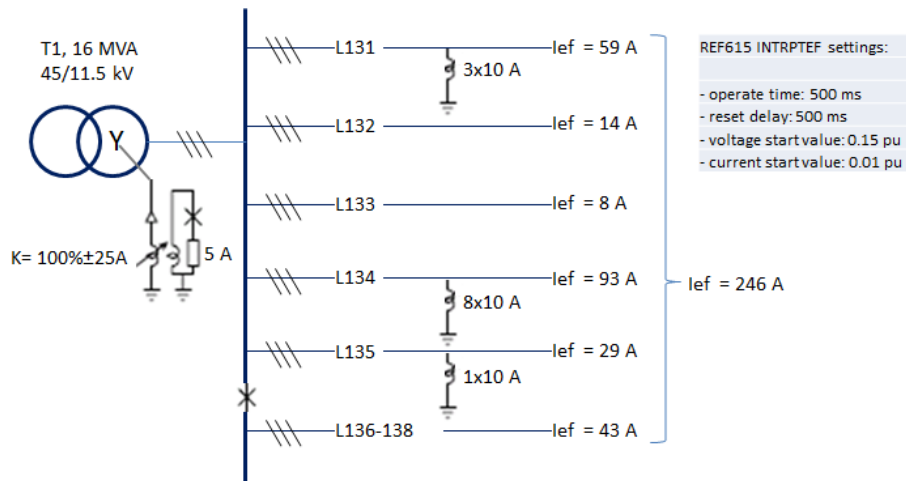


Fig. 6 Network parameters of the studied substation and applied setting values

detection. The BLOCK_EF-output can be used to block the traditional earth-fault protection functions in order to secure non-operation of the healthy feeder during a restriking earth-fault.

RELIABILITY PROVED BY COMPREHENSIVE SIMULATIONS AND FIELD TESTS

In recent years, ABB Oy, Distribution Automation, Finland has undertaken intensive field testing in co-operation with some power utilities in order to test and develop new earth-fault protection functions. The proposed algorithm has been intensively tested with actual disturbance recordings representing a wide variety of network and fault conditions.

The latest field test took place in a 10 kV HV/MV-substation owned by Vattenfall and located in Sweden. The network represented a large cable network with central and distributed compensation. **Fig. 6** shows the most important network parameters from the earth-fault protection perspective and the applied main settings of the INTRPTEF function during the tests. The operation of novel earth-fault protection was demonstrated by totally 51 individual test cases,

in which the fault type (permanent, restriking), location (totally four different fault locations) and the compensation degree was varied (undercompensated, fully compensated and overcompensated). The novel algorithm provided correct operation in all cases. The results prove that the overall security and dependability of the protection can be significantly improved compared with the traditional restriking earth-fault protection functions.

The new functionality is now available in 4.0 version of the very popular 615 series protection and control relays for distribution networks and in particular the Feeder Protection and Control REF615.

Authors: Ari Wahlroos, Janne Altonen, ABB Oy, Medium Voltage Products.

1MRS757842 A, © Copyright 2012 ABB. All rights reserved.

ABB Oy, Medium Voltage Products
P.O.B 699
65101 VAASA, FINLAND
<http://www.abb.com/substationautomation/>