Simulation of a zero-sequence relay for a distribution network with EMTP-RV
Discrimination between fault current and magnetizing inrush current

M. Petit, P. Bastard

Abstract-- The zero-sequence relays are widely used to protect radial feeders of distribution network against grounded faults. When a fault is detected a reclosing sequence is often used to suppress the fault. If these feeders are connected to MV / LV transformers, the closing relay generates a magnetizing inrush current. Then the current transformers saturation induces an apparent zero-sequence current that can be seen as a fault current by the relay. To prevent the relay opening the 100 Hz positive sequence can be used. The delay between the 100 Hz positive-sequence and the 50 Hz zero-sequence can help to discriminate fault current from magnetizing inrush current.

In this paper a complete simulation of such a relay with EMTP-RV is described using both the power and control blocks available in the EMTP-RV library.

Keywords: zero-sequence relay, distribution network, fault current, inrush current.

I. Introduction

THE energizing of a power transformer can generate high transient inrush currents due to a core saturation. This phenomenon depends on several parameters such as the core residual magnetization and the switching instant. Moreover the inrush currents are often poorly measured due to the saturation of the current transformers (CT). A brief analysis of the magnetizing inrush phenomenon is reviewed in [1].

The transformers inrush currents are an important problem for the reliability of the protection relays:

- differential relay for power transformer protection because inrush currents induce a false differential current,
- zero-sequence relay for radial feeder with transformer connected because inrush currents saturate the CT and then induce a false zero sequence current that trips the relay.

The relay must not trip during inrush conditions to ensure the service continuity of the energy and to prevent internal fault (tripping the transformer during an inrush current generates high overvoltage that may be critical for the insulator and then cause an internal fault).

The inrush currents also induce mechanical stress that can be dangerous for the transformer life-time and then the power network security.

Many papers have been published to study the inrush currents with three points of view:

(i) improve the discrimination between a fault current and an inrush current with the aim to prevent a false tripping and then to improve the energy quality. Several methods have been proposed to detect an inrush current. A classical method compares the magnitude of the second harmonic with the magnitude of the fundamental frequency component of the differential current. Above a fixed threshold level (generally 15 – 20 %) an inrush current is detected and the relay is inhibited. But such a simple algorithm has some limitations [1]. Improvements have recently been proposed. [2] uses the angular relationship between the first and second harmonics of the differential current, [3] uses a criterion based on the time variation of the second harmonic of differential current. New methods using wavelet [4] or neural network coupled with an FFT analysis [5] are also proposed.

(ii) reduction the inrush currents. As they are a problem for the relays' reliability a solution is to reduce them. Several solutions have been proposed. [6] increases the transient inductance of the primary coil, [7] proposes to use a virtual air gap with the AGW (air gap winding) technique and [8-10] controls the switching instant.

(iii) impact on the mechanical stress. This side effect of the inrush current is investigated in [11], [12].

The major part of the studies mainly focuses on differential relays. In the present paper we will focus on a zero-sequence relay that protects a radial feeder of a MV network with MV/LV transformers connected. Our goal is to discriminate the three following situations:

- fault current,
- inrush current with fault
- inrush current without fault

The relay must trip in the two first situations.

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II. Description of the Simulated Network

The algorithm has been tested with the radial 3-wires MV network described in fig. 1. A HV source (63 kV, 560 MVA) feeds a step down transformer (63 kV / 20 kV, Yyn, 30 MVA) through a 2 km HV line. The HV/MV transformer is resistively grounded with R_N = 40 Ω.

The MV busbar feeds two aerial feeders:

(i) a sound feeder connected to a 500 kVA charge (with a 0.9 power factor) through a 20 km aerial line.

(ii) a faulty feeder connected to a 100 kVA charge (with a 0.9 power factor) and nine MV/LV transformers (20 kV / 400 V, Dyn, 630 kVA) at its end. The feeder' length is 20 km with the fault at the middle of the line. The magnetizing saturation of the MV/LV transformers is modeled with a non linear inductance put on the LV side.

The faulty feeder is protected by a zero-sequence relay (fig. 2) which measures the three line currents on the secondary side of three CTs (120 A / 4 A). The magnetizing saturation of the CTs is modeled with a non linear inductance put on the primary side (fig. 3). The three breakers are commanded the relay's algorithm.

All lines are modeled as CP lines continuously transposed and power transformers (3 legs) with RL coupled models from the BCTRAN routine. The CTs are modeled with 1-phase ideal transformers.

III. Zero-Sequence Relay

A zero-sequence relay detects a fault to ground as soon as the zero-sequence current is above a defined threshold. For aerial lines most of fault to ground are transient faults, i.e. a reclosing sequence with a 300 ms opening is often enough to clear the fault. But transformers connected to the feeder can induce problems when the breaker is reclosed. The transformers re-energization induces inrush currents with peak values of about ten times the nominal value. As the primary windings of the MV/LV transformers are delta connected the real zero-sequence current is null, so the relay should be

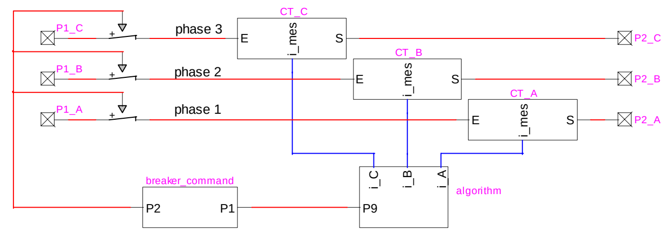

Fig. 2. Protective relay with the three CTs, the algorithm and the breaker's command.

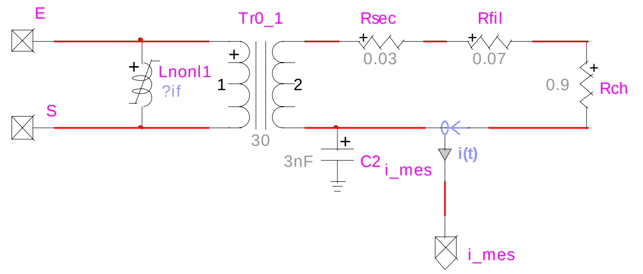

Fig. 3. CT modeling. R_{sec}, R_{fil} and R_{ch} are respectively the secondary winding, cable link and charge resistances (values are in ohms). The total resistance is $R_t = R_{sec} + R_{fil} + R_{ch} = 1.0\ \Omega$

inactive. But the phase currents are measured on the secondary windings of the CTs, while the CT is unsaturated:

$$i_{prim} = i_{sec}\ ,\ v_{sec} = R_t i_{sec} = \frac{d\phi_{CT}}{dt} \text{ and } \phi_{CT} = R_t \int i_{sec}(t)dt$$

When there is an inrush current the peak value of i_{prim} is high and the CT flux ϕ_{CT} will increase up to the saturation, then i_{sec} drops to zero. As the inrush currents of the three phases are dissymmetric (because the three poles of the breaker close simultaneously) the three CT will not saturate at the same time. Once the first CT saturates the measured residual current is no more null. We can notice that this false residual current appears with a delay after the line reclosing, this delay is the time before the first CT saturates. A false zero-sequence current appears and the relay may trip the breakers. To prevent such a mal-operation, a restraint algorithm using the 100 Hz positive sequence current is used.

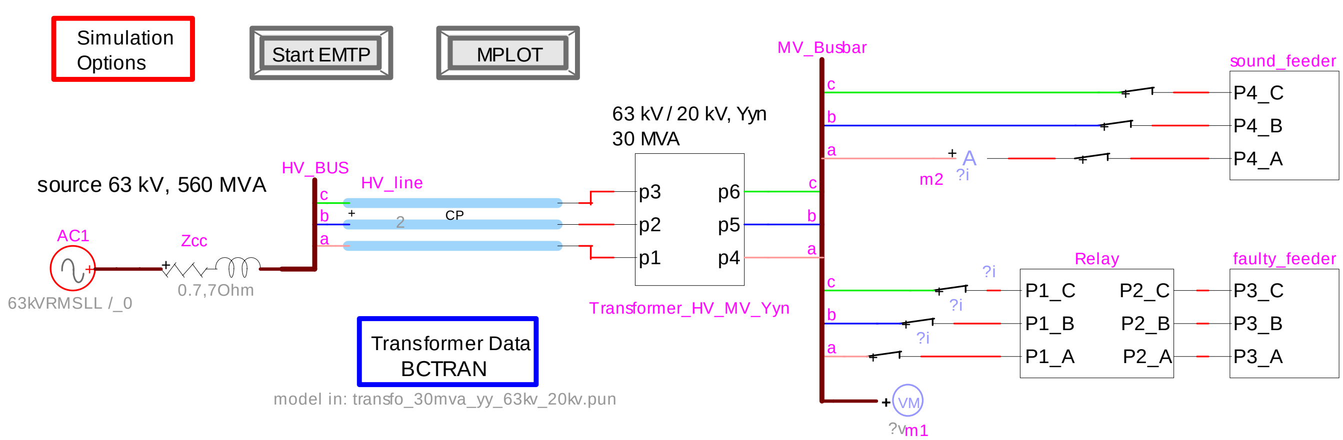

Fig. 1. Radial MV network fed by a HV line through a 30 MVA transformer. The studied relay protects the faulty feeder.

IV. Restraint Algorithm

The proposed algorithm uses the delay between the positive sequence 100 Hz current and the false zero-sequence current which is characteristic of an inrush current without a fault. If the fault is permanent, the feeder reclosing generates an inrush current with fault, and then there is a real zero-sequence current simultaneously with the positive sequence 100 Hz current. The sequence currents are calculated through a 20 ms width sliding window. Our algorithm needs three parameters:

- detection threshold of the zero-sequence 50 Hz current,
- detection threshold of the positive sequence 100 Hz current,
- threshold value for the delay between the crossings of the previous thresholds.

For our example we chose 10 mA for the currents thresholds and 2 ms for the threshold delay. The algorithm is represented in fig. 4 with the blocks of the EMTP-RV library.

When the zero-sequence current becomes higher than the threshold, the comparator output (COMP_1) is set to “ 1 ” and a 20 ms-width pulse is generated. It is the same for the positive sequence 100 Hz current. The two pulses are sent to the inputs of a XOR logical function (Fm3). The output of Fm3 is a pulse with width equal to the delay between the threshold crossings of the positive and zero sequence currents. If this delay is less than the delay threshold (2 ms), the AND logical function (Fm5) generates a pulse that will open the breaker: an inrush current with a fault is detected.

V. Results

Now let us look at the algorithm’s behavior to discriminate inrush current with a fault and without a fault during a reclosing sequence.

A. Inrush current without a fault

The breaker is open after a transient phase-to-ground fault detection and is reclosed at t = 403.2 ms. After the reclosing the $I_{thres\_pos\_100Hz}$ threshold is crossed immediately, (1), and the $I_{thres\_zero\_50Hz}$ threshold is crossed at t = 413.4 ms with a 10 ms delay, (2). The command signals in Fig. 5 show that there is no

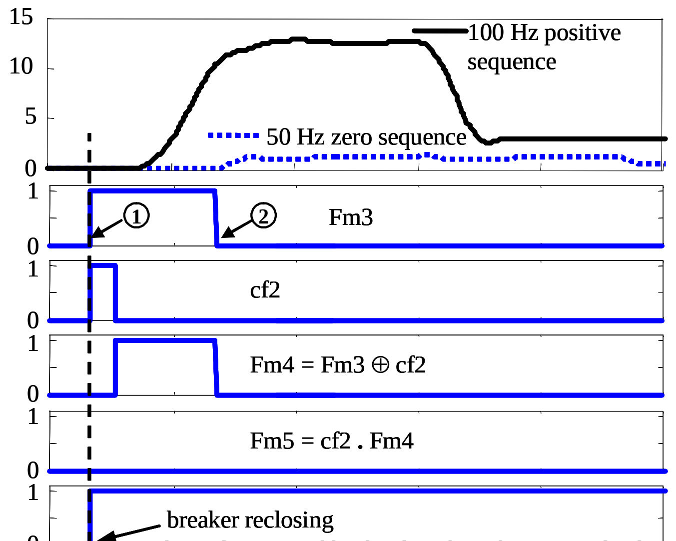

Fig. 5. Command signals generated by the algorithm. Phasors’ amplitudes of the zero and positive sequences currents in Ampere. No pulse for Fm5 ➔ the breaker remains closed.

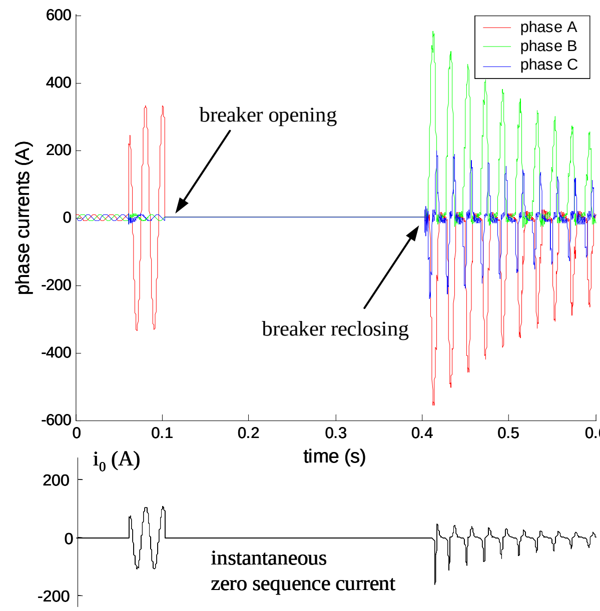

Fig. 6. Phase currents for a reclosing sequence with a transient fault.

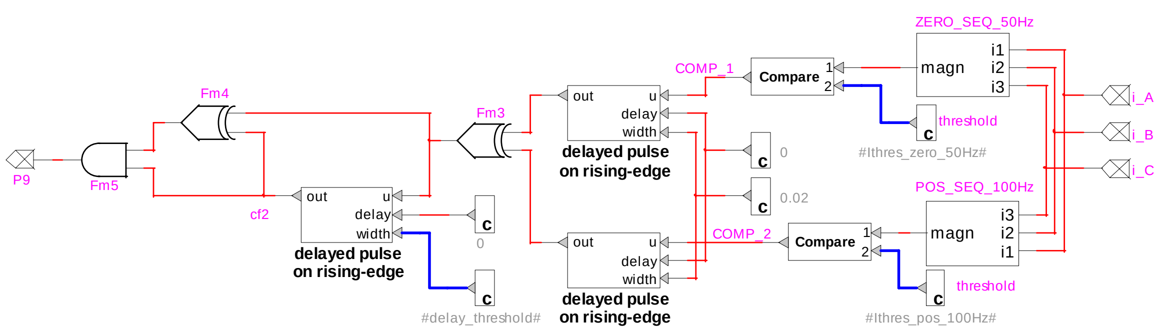

Fig. 4. Algorithm to discriminate an inrush current. The input parameters are $I_{thres\_pos\_100Hz}$, $I_{thres\_zero\_50Hz}$ and *delay_threshold*. In the present paper the parameters values are respectively: 10 mA, 10 mA and 2 ms.

pulse generated by Fm5, so the breaker remains closed. The phase currents, during the complete reclosing sequence, are plotted in fig. 6. In the same figure the instantaneous zero sequence current measured by the CTs is plotted. This current is similar to the on-site registered data (fig. 7).

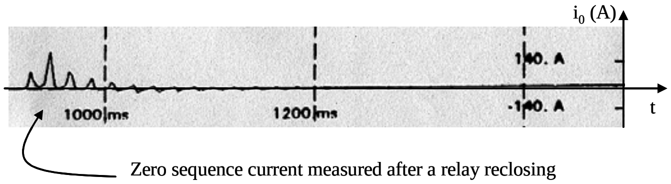

Fig. 7. instantaneous zero sequence current measured by a relay after a reclosing without fault. The effect of the inrush current clearly appears on these on-site registered data.

B. Inrush current with a fault

The phase-to-ground fault is permanent, the breaker is open after its detection and is reclosed at t = 403.2 ms. After the reclosing the $I_{thres\_pos\_100Hz}$ threshold is crossed at t = 403.27 ms and the $I_{thres\_zero\_50Hz}$ threshold is crossed at t = 403.53 ms with a 0.3 ms delay. Here the fault induces a real zero sequence just after the reclosing. The command signals in Fig. 8 show that there is a pulse is generated by Fm5, so the breaker re-opens after a 40 ms delay. The phase currents are plotted in fig. 9

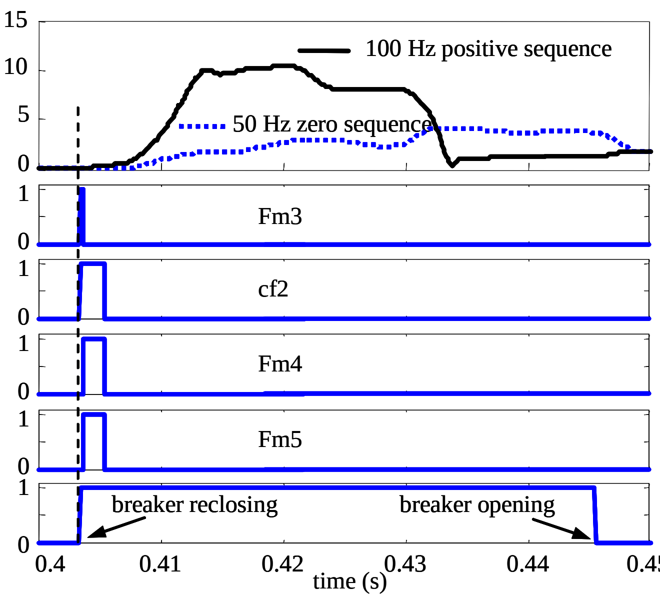

Fig. 8. Command signals generated by the algorithm. Phasors' amplitudes of the zero and positive sequences currents are in Ampere. Pulse for Fm5 ➔ the breaker is re-opened with a 40 ms breaker delay

C. Phase-to-ground fault

The present algorithm can also be used to detect a phase-to-ground fault because the calculation of the phasors through a 20 ms width window generates a false 100 Hz positive sequence during the transient regime (fig. 10). This sequence current reaches the threshold simultaneously with the zero sequence. It was applied in fig. 6 and 9 to detect the fault at t = 61 ms.

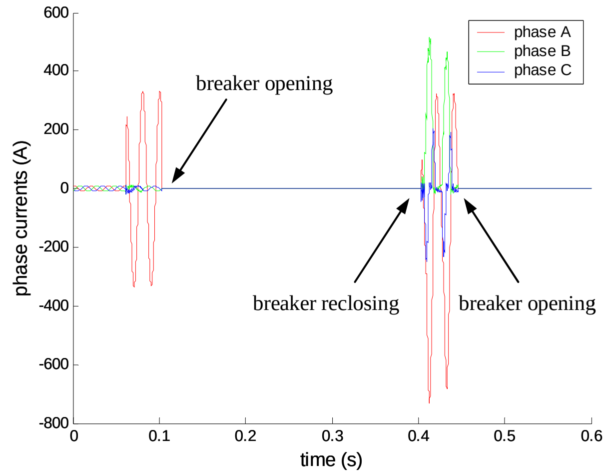

Fig. 9. Phase currents for a reclosing sequence with a permanent fault

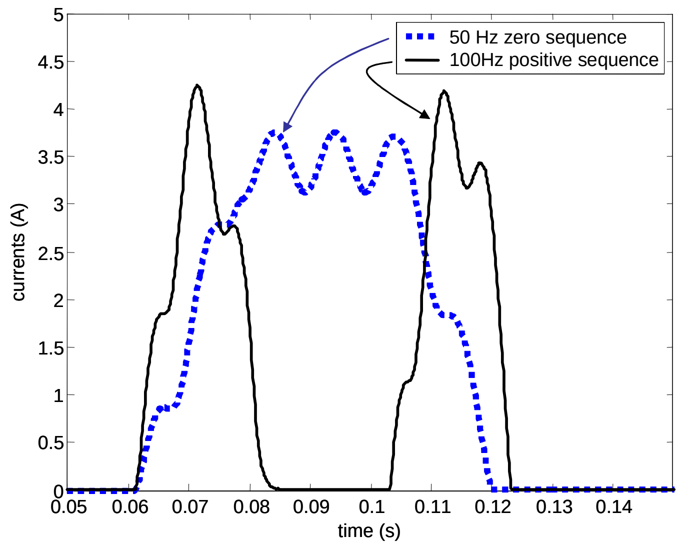

Fig. 10. 50 Hz zero sequence and 100 Hz positive sequence during the fault. The currents are calculated through a 20 ms width window.

VI. CONCLUSIONS

The detection of inrush currents is an important issue for protection relays manufacturers because it can generate mal-operations. In this paper we focused on a zero-sequence relay that protects a MV aerial feeder with MV/LV transformers connected. Such a relay can mal-operate due to the saturation of the CTs which generates a false zero sequence current and then trips the breaker. A simple method using the delay between the 100 Hz positive sequence and the 50 Hz zero sequence currents is used to discriminate an inrush current from a fault. This algorithm needs three parameters: (i) a threshold of the zero-sequence 50 Hz current amplitude, (ii) a threshold of the positive-sequence 100 Hz current amplitude and (iii) a threshold value for the delay between the crossings of the previous thresholds.

An inrush current with a fault or a fault alone are characterized with a very short delay between the two threshold crossing (less than 2 ms), whereas the delay is higher than 2 ms for an inrush current without a fault. This is the criterion used in this paper. The relay was fully simulated with the new EMTP-RV using both power and control blocks.

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VIII. Biographies

Marc Petit was born in Deville les Rouen (France) on October 25, 1972. He is a former student of the Ecole Normale Supérieure de Cachan (south of Paris) and received a Ph-D degree in 2002 from the University Paris XI – Orsay. He joined SUPELEC in 2003 as an assistant professor and works in the Power Network group.

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