# A MHO distance relay device in EMTPWorks

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**Abstract-- Distance relays are widely used for protection of transmission lines. Usually, the nonlinear nature of an arcing fault requires that a time model should be implemented to know if the relay detects or not this faulted condition. Moreover, the mutual effect of line conductors for single or multiphase faults requires that all three phases of the relay be modeled. This paper describes in detail a first generic MHO distance relay in EMTPWorks based on three separate single phase impedance vectors. Cosine-sine filters are used to perform the phasor representation of the fundamental current and voltage computed over a 60 Hz sliding time window. Validation of the measured impedance function of the model is compared with the real apparent impedance of the network. This paper also discusses logical operations to initiate the opening of line breakers.**

**Keywords:** MHO distance relay, EMTP-RV, protection

## I. Introduction

Studying relay performance during single phase or multiphase faults requires EMTP type programs to replay events and analyze problems (see [1]-[3] and [4]). With the EMTPWorks GUI (of EMTP-RV [5][6]), complex control functions and power devices are visualized easily solved with the EMTP-RV engine. The characteristic of the presented MHO relay is based on the following equations:

$$Z_{PG} = V_{PG} / (I_L + 3*K*I_0) \quad (1)$$

$$K = (Z_0/Z_1 - 1) / 3 \quad (2)$$

where $Z_{PG}$ and $V_{PG}$ are respectively phase-to-ground impedance and voltage; $I_L$ and $I_0$, the 50-60Hz line and zero sequence currents; $Z_0$ and $Z_1$ the zero and positive sequence line impedances. The role of these equations is to keep $Z_{PG}$ invariant with the type of the fault, single-phase or double-phase to ground.

Three single phase $Z_{PG}$ values are evaluated. For each phase three logical outputs based on the penetration in three impedance circles are transmitted.

## II. General structure

From AC measurements to logic outputs, the general structure of the relay is shown in Fig. 1 to Fig. 4. It is identical for each phase. The logic diagram begins with theses functionalities:

- U (voltage) phase-ground and I (current) line meters are inputted to an optional $2^{nd}$ order AC filter; these filters could be switched off if necessary
- Ideal 3-ph to zero sequence phasor transformation
- Vector calculation of $Z_{PG}$

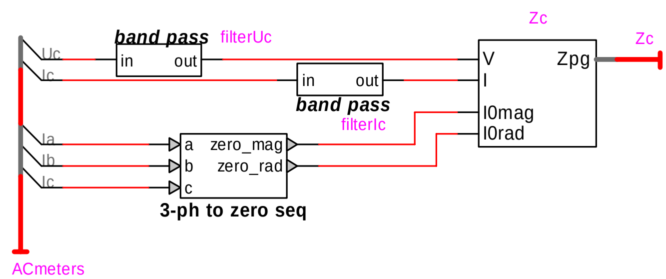


**Fig. 1 AC meters to $Z_{PG}$ subcircuit connections.**

From the circle impedance parameters given by the user, nine subcircuits determine if $Z_{PG}$ goes inside theses zones for a given duration. This duration given by the user is the sum of the breaker operational time (2 or 3 cycles) and the implemented time delay. For each phase, three circles are defined with the same angle definition; two are shown below in Fig. 2.

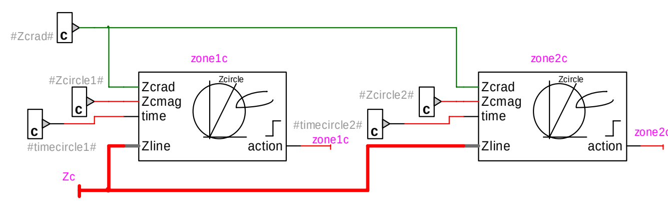


**Fig. 2 $Z_{PG}$ with logical outputs for two zone**

Fig. 3 indicates how for each phase, the three logical outputs are entering in an OR logic function connected to the breaker.

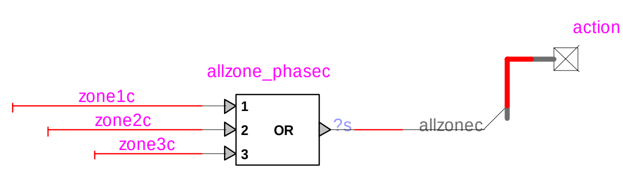


**Fig. 3 Outputs from three zones to breaker trigger action**

Fig. 4 illustrates how the logical output is used to perform single or three pole CB opening scheme. The `c3phSW1` device is simply built with three single phase controlled switches.

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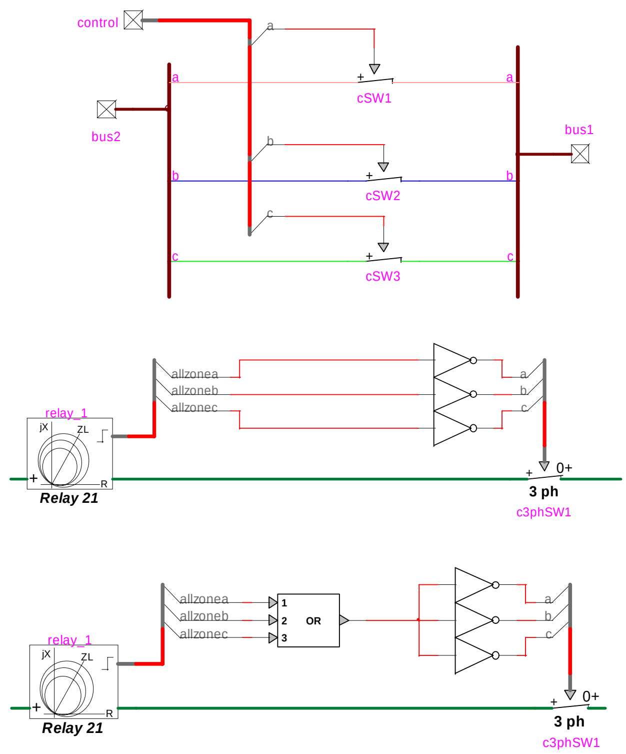


**Fig. 4 From relay model to controlled switch. Single-pole and three-pole opening breaker.**

## III. $Z_{PG}$ IMPEDANCE DEVICE

This is the main device in this MHO relay device. The voltage and the current represented with 60 Hz phasors are synthesized with an ideal cosine-sine transformation included in the EMTPWorks library. X is the real part, Y the imaginary part and k the harmonic rank.

$$x = \frac{2}{period} \cdot \int_{t-period}^{t} in(t) \cdot \cos(k \cdot 2\pi \cdot freq \cdot t) \cdot dt$$

$$y = \frac{2}{period} \cdot \int_{t-period}^{t} -in(t) \cdot \sin(k \cdot 2\pi \cdot freq \cdot t) \cdot dt$$

Fig. 5 and Fig. 6 show the $Z_{PG}$ device realized with a dozen standard EMTPWorks devices. The zero current compensation is a vector summation and the vector operations are realized with devices from the phasor library. An extra test (not showed here) is made on $I_{mag}$ if current is higher than the burden of the relay or otherwise the relay is blinded.

Extras functions are shown in Fig. 6. After the Z-phasor-divide function, two first order DC filters are applied on magnitude and angle signals, for t=5 ms. The angle is limited between –PI and PI. The reason is that the zone detection subcircuit algorithm illustrated in Fig. 7 requires an angle defined between $-\pi$ and $\pi$ to work correctly.

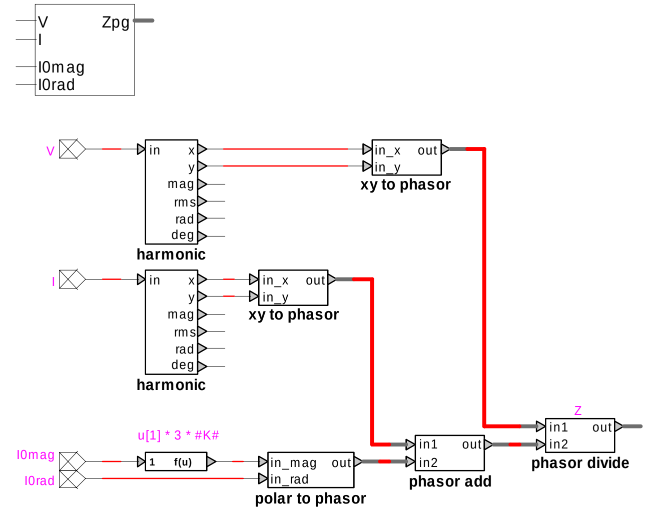


**Fig. 5 Control diagram of $Z_{PG} = V_{PG}/ (I_L + 3*K*I_0)$**

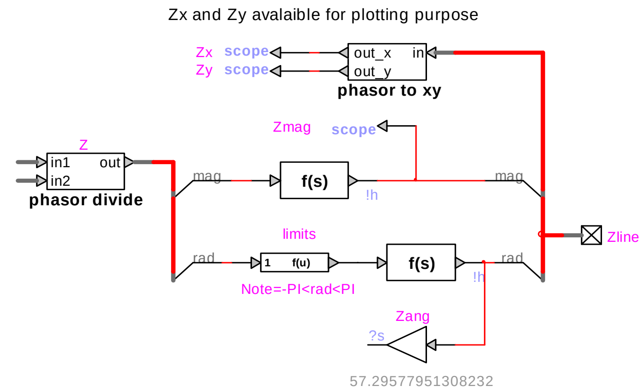


**Fig. 6 Extra functions before $Z_{PG}$ usage**

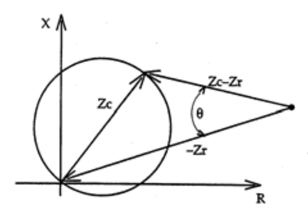


**Fig. 7 Geometric approach for decision. Zc: circle impedance vector; Zr: impedance vector seen by the relay.**

## IV. ZONE DETECTION

This subcircuit requires $Z_{PG}$ representation in the complex domain and the circle parameters. The algorithm used in our model to detect a fault is based on this rule: if $Z_r$ is entering the circle, the angle θ between $-Z_r$ and $Z_c$-$Z_r$ must be superior to 90º. This geometric rule is illustrated in Fig. 7.

In addition with the mathematical function, the subcircuit illustrated in Fig. 8, includes a generic subcircuit called `relay` which estimates if θ is higher than 90 degrees for a certain time, in accordance with the time delay parameters `timecircle1`, `timecircle2` or `timecircle3`.

In Fig. 9, the `relay` circuit has a gain before a resetable integral when its output is greater or equal to 1 only when the time is equal or greater to delay value.

Finally, a section of the distance relay device is provided for plotting the three circle zones in the R-X domain. In Fig. 10, the XY offsets are defined to force the circle to pass by the (0,0) point.

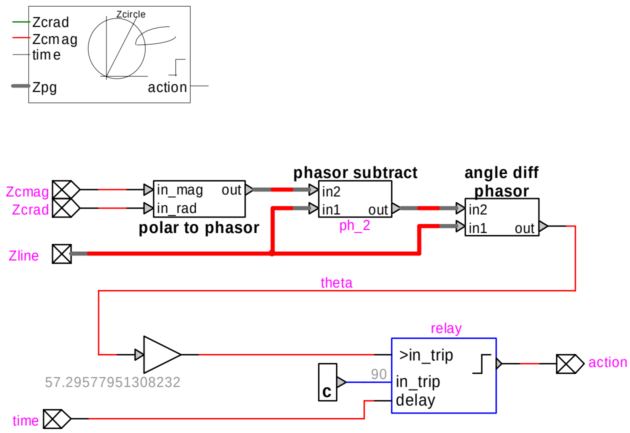


**Fig. 8 Inside the zone detection subcircuit.**

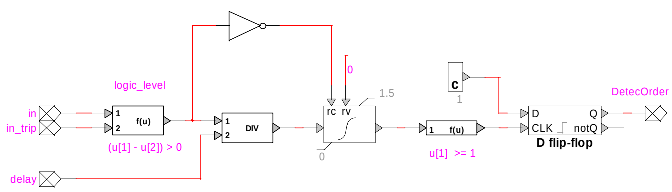


**Fig. 9 Inside the relay subcircuit colored in blue in Fig. 8.**

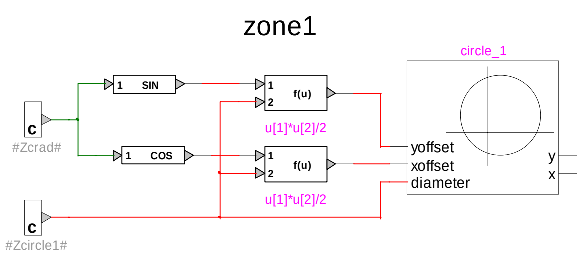


**Fig. 10 Extra function for R-X plotting.**

## V. $Z_{PG}$ VALIDATION

This conventional MHO relay device requires only a few parameters as shown in Table below. The user has to set the three zones of the circle data – diameter and delay, plus the line impedances R1, X0, X1 used for zero sequence current compensation K and the angle of the three circles. The initial impedance load is given to avoid errors during the first cycle of the simulation.

When the zero sequence current compensation is well calibrated, $Z_{PG}$ is invariant for the type of fault. To verify this statement, the test circuit in Fig. 11 is simulated for five sequential temporary faults:

- 3Φ-GND 1-1.5 s, 1Φ-GND 2-2.5 s, Φ-Φ 3-3.5 s, Φ-Φ-GND 4-4.5 s and a floating 3Φ fault 5-5.5 s.

The theoretical impedance value is 40Ω∟87.8º. The three single phase impedance outputs demonstrate the *unaffected* impedance value according to the type of fault except the phase to phase fault where the magnitude has an error of 25% (50 Ω vs 40Ω). This limitation of the model is associated with the phase to ground voltage measurement approach.

Table 1 **Parameters required by the mho relay device.**

| **Parameters** | Units | |
|---|---|---|
| Zr_init_mag (initial load) | Ω | 325 |
| Zr_init_rad | rad | -0,12 |
| X0 | Ω/km | 1,1 |
| X1 | Ω/km | 0,3250 |
| R1 | Ω/km | 0,0122 |
| Zpg_mag (line impedance) | Ω | 80 |
| Zcircle1_pc | % | 80 |
| timecircle1 | s | 0,04 |
| Zcircle2_pc | % | 120 |
| Timecircle2 | s | 0,40 |
| Zcircle3_pc | % | 200 |
| Timecircle3 | s | 1,50 |
| Notch filters, second order | | |
| fn | Hz | 60 |
| zeta | | 0,707 |

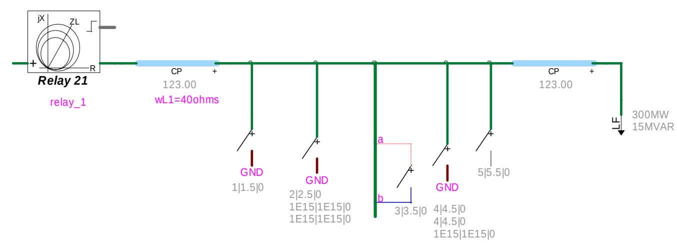


**Fig. 11 Test circuit for impedance $Z_{PG}$ calculation.**

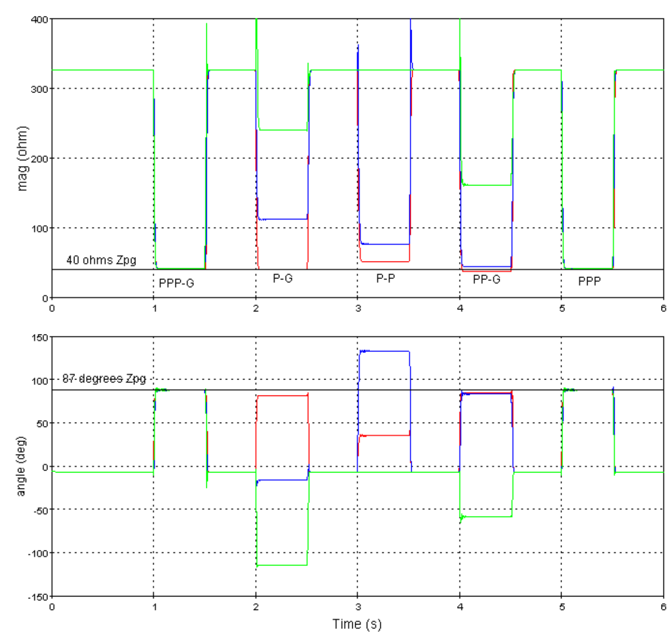


**Fig. 12 Five sequential faults, for each phase impedance magnitude and angle estimation. A-red, B-blue, C-green.**

## VI. MHO DISTANCE RELAY VALIDATION

The following circuit tests the relay device with a 0 Ω fault on phase A. According to the visible ModelData attribute, $Z_{PG}$ on phase A goes inside the second and third zone circles and the other phase impedances stay outside; the controlled switch opens the phase A after a delay of 0.4 s from the beginning of the fault.

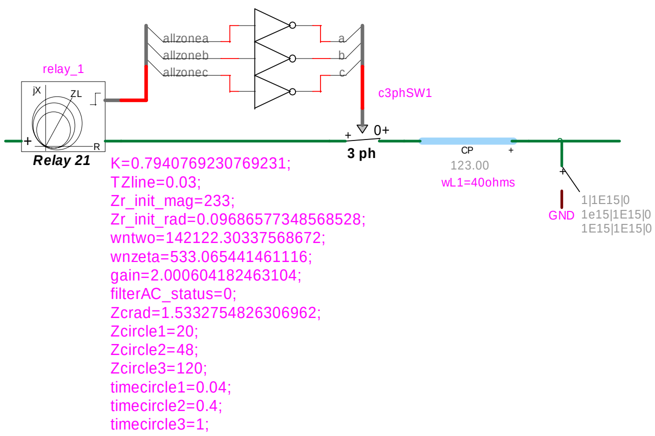


**Fig. 13 Test circuit for zone and timer**

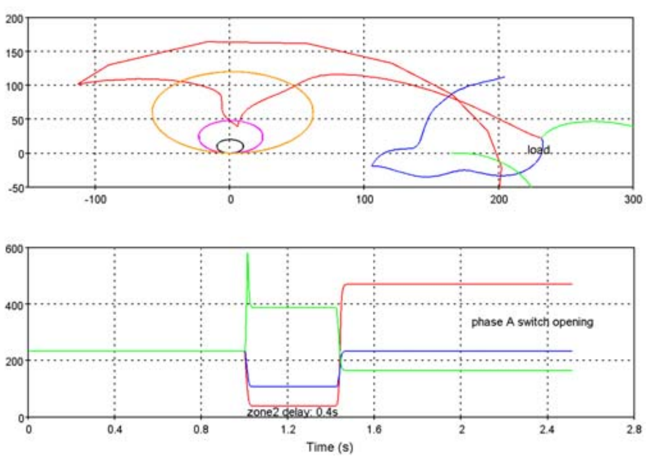


**Fig. 14 Three zones and the phase trajectory – single phase opening. A-red, B-blue, C-green.**

This third test circuit shown in Fig. 15 is constructed to evaluate the impact of a resistive fault on relay measurements. This highly resistive fault doesn't touch the limit of the third zone circle. That explains why resistive faults are difficults to detect by the conventional MHO pattern.

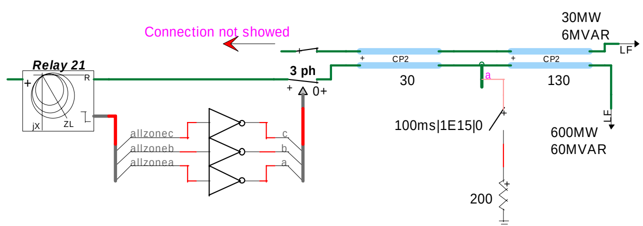


**Fig. 15 Resistive fault test circuit.**

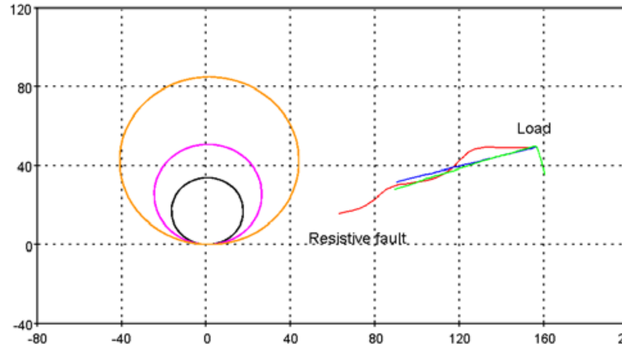


**Fig. 16 Phase to ground resistive fault. Three zone relay and impedance magnitude trajectory. A-red, B-blue, C-green.**

## VII. CONCLUSIONS

A generic MHO distance type relay was developed and tested in the EMTPWorks environment. A minimal set of functions has been assembled from AC measurements to the logical outputs. The impedance algorithm works for all types of faults except phase-to-phase where a magnitude error of 25% is introduced. This first relay version helps the users to visualize potential problems. Protection engineers may add features like CT characteristics and their burden, phase to phase voltage measurements, reclosing functions; other zone characteristics such as lens or parallelograms, etc.

## VIII. REFERENCES


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[6] J. Mahseredjian and C. Dewhurst: "EMTPWorks, Graphical User Interface of EMTP-RV", 2005, Version 2.0.2


## IX. BIOGRAPHIES

**Luc Gérin-Lajoie** received his B.A.Sc. in Electrical Engineering from École Polytechnique de Montréal in 1982. From 1982 to 1985, he worked for Hydro-Québec in System Planning of the 120 kV network. He then joined the Control and Protection team in the Systems Studies Department. His responsibilities include protection/automatism specification, modal analysis, optimization and control coordination, as well as electromagnetic phenomena and analytic studies related to the performance of SVC and synchronous machine on the bulk transmission system. He also contributed, for Hydro-Québec, to the validation of the new EMTP-RV and participated in the development of EMTPWorks models.