# ADVANCED DISTANCE RELAY MODELING AND TESTING

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## *ABSTRACT*

Automatic test sets have become common tools for those who are involved in relay testing. The reason of this great success is in part due to the introduction of the microprocessor, in part to the necessity to provide a better quality of the energy provided by the utilities. The quality program now requires a constant monitoring of all devices in service. Moreover, the increasing demand of energy requires more and more installations, with a constantly increasing number of devices to install and to check time to time.

The increasing number of devices to be checked and the personnel reduction force companies to pretend an even faster service: verifying relays is part of this service and the faster is done the better it is.

Among the new challenges, technicians have to face other

- More complex impedance relay characteristic
- More complex differential relay characteristic
- Increased number of functions to test
- Intelligent devices requiring a more accurate simulation of the electrical phenomena occurring in the electrical system.

We will address some of them in this paper:

1. New distance relay modeling
2. Automatic DC offset generation


## DISTANCE RELAY MODELING

Nowadays, modern distance relays have very complex characteristics unlike the old circular MHO shapes.

Without proper tools, modeling certain relay characteristics might be challenging for any expert protection engineer. It requires a deep knowledge on how the relay setting influences the operating characteristic. And even so, a manual modeling of the characteristic as a sequence of lines and/or arcs might become highly time consuming.

For this reason, many relay test set manufacturers are providing software tools to automatically draw the impedance characteristic of a large number of relay models based on their settings. Advanced features like multiple earth factor, arc resistance compensation etc, must also be taken into account.

Now, if we consider very complex characteristics like the one displayed in this picture, which refers to a Toshiba GRZ100, we will understand that the definition of the nominal char is a combination of lines and arcs and user should calculate all parameters related to the each section of the char.

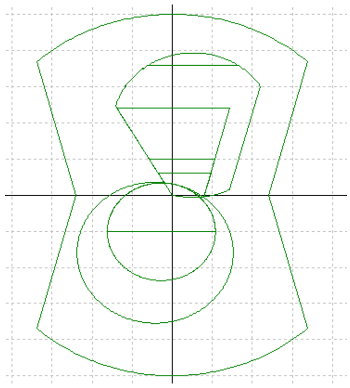

**Figure 1**

The typical structure of a RIO file is a list of lines and / or arcs

```
A mixed char
BEGIN SHAPE
  LINE  5, 0, 90
  LINE  5, 1.25, 180
  ARC  0, 0.625, 0.625, 90, 270
  LINE  0, 0, 0
END SHAPE
```

However, distance relays usually treat the zones in a different way. Each line is associated to a comparator. The logic combination of different comparators will lead to defining the zone shape.

In this example we have 4 linear comparators

1. $R \leq R_{fwd}$
2. $X \leq X_{fwd}$
3. $X \geq X_{rev}$
4. Etc

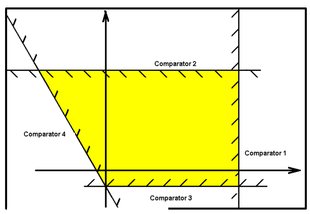


**Figure 2**

More complex characteristics are the combination of quad and mho characteristic. The Toshiba GRZ100 for instance has

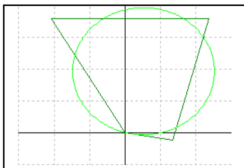

Figure 3

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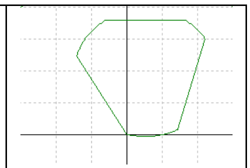


Figure 4

For the relay it is a simple operation since it will require the addition of another comparator: the circular one.
For the user it is not evident how this sequence of arcs and lines is defined

**LINE 7.212389, 0.7926472, 75**
**ARC 2.588202, 9.659244, 10, 32.45674, 56.51973**
**LINE 8.1047, 18, 180**
**ARC 2.588191, 9.659257, 10, 123.4804, 165**
**LINE -7.071067, 12.24745, -60**
**LINE 0, 0, -10**
**ARC 2.58819, 9.659258, 10, 265, 297.5433**

However, if the modeling software allowed the definition of a zone as a result of the combination of two or more shapes, the user will have a super powerful tool to simply define the above shape as the intersection between two or more shapes,

$$\text{Zone 1} = Z1_{MHO} \cap Z1_{QUAD}$$

Or even the combination of two or more shapes,

$$\text{Zone 1} = Z1_{MHO} \cup Z1_{QUAD}$$

Similarly, in the SEL321 and SEL421 for instance we may have:

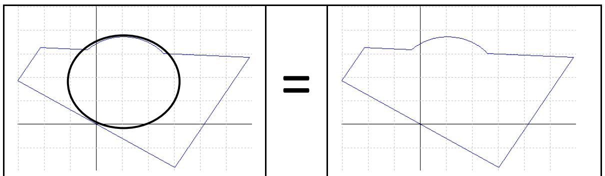



Figure 5 Figure 6

How would the two shapes be used during testing? The point is very simple. If zone 1 is the combination between two shapes like in this example, the nominal value at a specific angle, say for instance 30°, would be the minimum between the nominal impedances calculated on each shape. This is evidenced in Figure 8 where for each specific angle we have

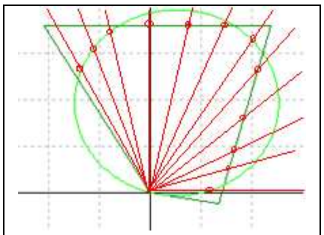
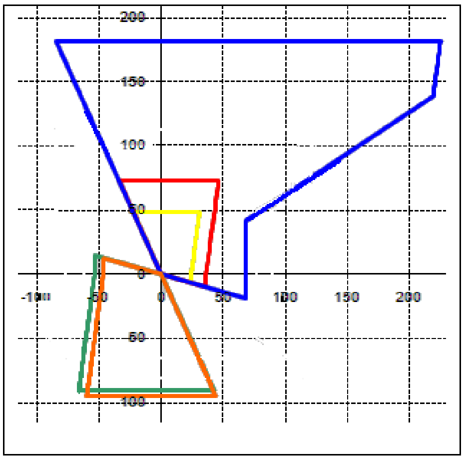


Figure 7

$$Znom = Min (Zquad, Zmho)$$

Another advantage is when treating effect of the load encroachment, or the general fault detection criteria, to the characteristic of the tripping zones. An example is the ABB REL670 relays, where the most external zone is chopped by the load encroachment.




## Conclusion

An advanced approach to distance relay characteristic definition is possible. This will enhance the productiveness of the technicians. However, it will unfortunately change the method of exporting the impedance relay nominal characteristic and formats like the actual RIO would be insufficient. In fact, although it makes possible to define whatever number of zones, it is not giving information whether a single zone is the combination of more shapes.

## DC OFFSET

Modern protective relays implement special algorithms to enhance the relay operating time in zone 1. A trip time below 1 cycle is required for EEHA lines. In order for these algorithms work properly, the currents seen by the relay must have a smooth change from pre-fault to fault:

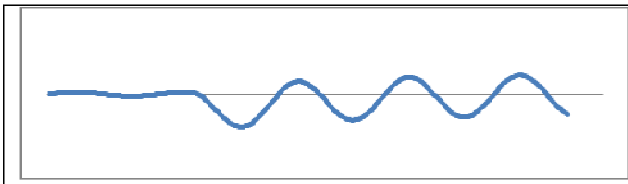


Figure 8

Modern protective relay test kits are able to reproduce DC offset with the help of simulation software like EMTP, or others with similar approach. But it is a method not easily applicable to automatic testing. In most cases, a pure sinewave is generated, and, to avoid the step changes on current, the zero crossing is used.

However, this method cannot be applied for instance to the three phase fault, as seen in figure 9

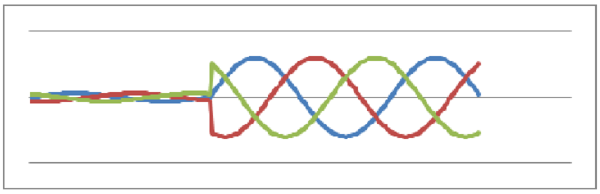


Figure 9

With these current waveforms, distance relays may not be able to apply the high speed algorithm and would therefore operate based on the slower normal algorithm.

A quote from Areva P443 user manual

Modern dynamic secondary injection test sets are able to accurately mimic real power system faults. The test sets mimic an instantaneous fault "shot", with the real rate of rise of current, and any decaying DC exponential component, according to the point on (voltage) wave of fault inception. Injections for all three phases provide a six signal set of analog inputs: Va, Vb, Vc, Ia, Ib, Ic. Such injection test sets can be used with the MiCO*Mho* P443, with no special testing limitations.

Conversely, older test sets may not properly simulate:

1. A healthy prefault voltage memory,
2. A real fault shot (instead a gradually varying current or voltage may be used),
3. The rate of rise of current and DC components,

A six signal set of analog inputs (instead, these may offer for example: Va, Vb, Ia, Ib only, to test for an A-B injection).
Such injection sets may be referred to as *"Static"* simulators. As the P443 relies on voltage memories and delta step changes as would happen on a real power system, certain functions within the relay must be disabled or bypassed to
allow injection testing. Selecting the "Static Mode" test option serves to bypass the delta phase selectors, and power swing detection. For the tests, the delta directional line is also replaced by a conventional distance directional line, and the digital filtering slows to use a fixed one cycle window. Memory polarizing is replaced by cross-polarizing
from unfaulted phases.
The Static Test mode allows older injection test sets to be retained, and used to commission and test the MiCO*Mho* P443.

**Note:**
Trip times may be up to ½ cycle longer when tested in the static mode, due to the nature of the test voltage and current, and the slower filtering. This is normal, and perfectly acceptable.

Therefore, using static method, operating time for zone 1 might be up to 10 ms longer than expected, and this might be a problem when investigating some performances of the distance relay.

## DC offset created with a COMTRADE FILE

In order to produce the right DC offset in a **shot** test, the first approach would be that of creating a sort of small COMTRADE file. Supposing

- Nominal Frequency: 50 Hz
- Prefault duration: 200 ms
- Max fault duration: 1000 ms
- Sampling rate: 1 kHz

The amount of data to be transferred to the instrument to perform a correct test with the right DC offset would be

50 Hz * (0.200 s + 1.000 s) * 1000 Hz * 2 bites * 6 channels = 720 kB

Using high speed comm ports it would take a very little time to upload this small COMTRADE record onto the instrument memory and then perform the test.

However, this method is not applicable to developing fault where the point on wave of the fault injection depends on the previous relay response. The COMTRADE file should have a sort of dynamic soul, which is not the case when speaking of traditional files.

Therefore, checking the reclosing function, for instance, might be challenging for any test instrument because the DC offset and the relative decay must be generated on the fly.

## DC offset created on the fly

Here the test set must act almost in real time and generate the output values based on this formula

$$I(t) = \sqrt{2} * I_1 * \sin(\omega t + \varphi) * \left(1 - e^{-\frac{t}{\tau}}\right) + I_0 * e^{-\frac{t}{\tau}}$$

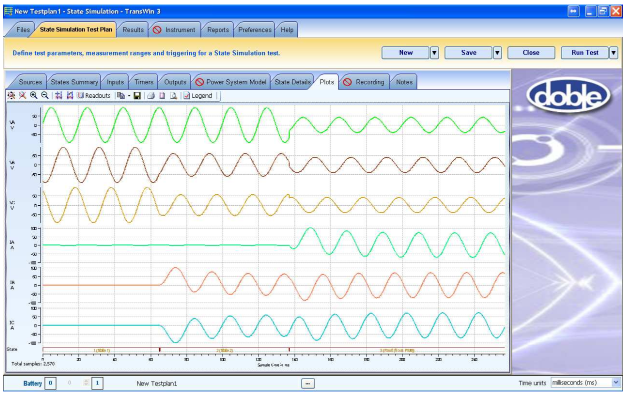
Where:

1. $I_1$ = RMS value of the fault current
2. $I_0$ = instantaneous value of the current just before the fault
3. $\tau$ = Time constant
4. t = Time in seconds, fault occurs at t=0

The above equation must be evaluated at high speed, say every 100 µs for a sampling rate of 10 kHz.
Since there are 3 currents for testing a distance relay, and 6 currents for testing a differential relay, it is evident the need of a high speed processors to enable such high computing power in a portable equipment.

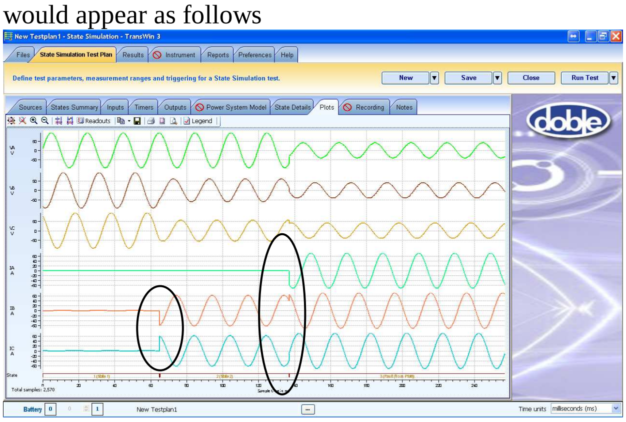
If the above equation is applied for every single sample of the output currents, it is easy to create test sequences where the DC offset are applied correctly, thus performing a deep check of the performances of the relay under test.

It is therefore enough to specify the time constant $\tau$ to the test since all other parameters are known.




The above is the simulation of a developing fault, where a phase to phase fault evolves into a 3-phase fault. The absence of instantaneous current changes enables the distance relay to operate correctly.

Without the proper simulation of the DC offset, the same would appear as follows




Please note the step currents.

## Conclusion

Protective relays are becoming smarter and smarter. Test equipments must also become smarter and smarter. The correct simulation of a fault is becoming an essential part of the test if we want to evaluate the relay performance in dynamic way.

## REFERENCES

[1] Quintin Verzosa, Jr., 2005, " Ground Distance Relays – Understanding the Various Methods of Residual Compensation, Setting the Resistive Reach of Polygon Characteristics, and Ways of Modeling and Testing the Relay ", *32nd Annual Western Protective Relay Conference, Spokane, WA, 25-27 October 2005*