A Novel Approach to Dynamic Test of Distance Relays

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Abstract:
Dynamic test is one of most important test methods for evaluation of performance of Distance Relays. The paper demonstrates a novel approach which deals with an algorithm of dynamic test through open loop simulation with helping of a PC.
It will be also explained the ways of obtaining Relay Specification through this approach. To apply signals, software interruptions in real time are used in this approach, which by itself is a new method in Relay Testers.

1 Introduction:

As power transmission network grows larger and larger, the protection of this system will become more important and more complicated. Transmission lines, as being exposed to various natural factors, are highly vulnerable to the fault occurrence.

The most common means of protection for transmission lines is utilization of distance relay, which due to its rapid response and simplicity of coordination with other relays in the network, is used as the main protection device for transmission lines with voltage class of higher than 63kV in Iran power system transmission lines.

To ensure the accurate performance of relays in critical conditions and fault occurrence, protective equipment are tested and their performances are evaluated at specific times. These testing events can take place at factory, after installation and prior to operation, or can be carried out periodically after operation.

One of the tests which is carried out in three period of relay testing, is test of relay through feeding from the secondary circuit of transformer, that means feeding the relay with similar voltages and currents to that of the secondary circuit of transformer[1].

As Distance Relay needs two input quantities, voltage and current, to be tested, its test is faced with some difficulties.

In the past, analog testers were used for testing Distance Relays, but due to their large volume and difficulty in their transportation, the need for new testers which could replace analog testers was felt seriously. By introduction of digital relays this need has increased and a tester was required which could evaluate all aspect of this type of relay accurately. At this stage, utilization of computer in the process of test has become more important than ever, and by entry of computer in the process of test, new test methods have been developed [2,3].

The main objective of dynamic test is to achieve computer characteristic of relay under various conditions of the network and faults. In analog testers, to carry out such a test, voltage and current are to be adjusted manually and on the event of fault occurrence their corresponding values have to be fed into relay. In the proposed method, for digital tester, voltage and current are calculated with the help of equivalent circuit and one needs only to introduce the elements of this circuit to the tester.

2 Open Loop Tester:

Fig. (1) illustrates a simple block diagram of an open loop tester.

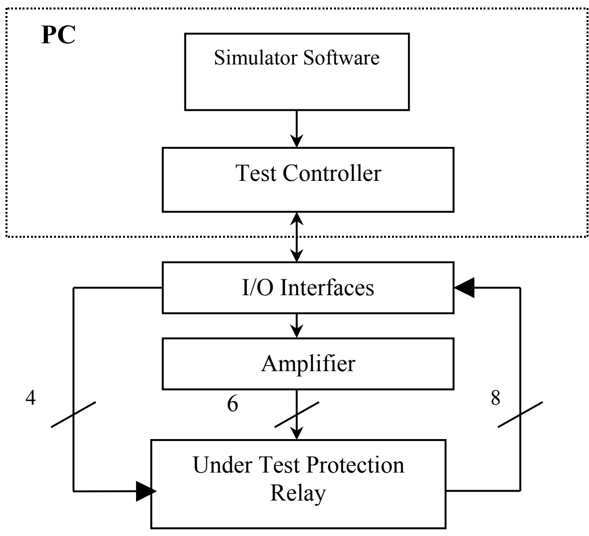

Fig.1 Open Loop Tester

As it is shown in this block diagram, Simulator Software computes the feeding voltage and current signals and save them. After changing the digital signals into analog, the controller unit, then reads and passes them to the amplifier.

In order to test a three phase relay, three voltage and current signals should be generated respectively, therefore, I/O interface card must have at least six analog output channels. Interface cards should also have eight digital inputs to track the outputs of the relay plus four additional digital outputs for generation of control signals.

To synchronize disconnection of switches on both sides of power transmission line, distance relay uses either of two schemes, namely, "Permission Over Reach" or "Permission Under Reach". These two schemes have to transmit communication signals from one side to another side of relay and aforesaid control signals are to meet this requirement [5].

This type of test is known as "Open Loop Test", because relay has no part in the simulation. In the software of simulator, different types of test can be carried out and results can be saved as if is instructed by the user.

One type of test that is used to calculate the specification curve of relay in R-X plane, is Dynamic Test, in which, the instant of fault occurrence is accompanied by voltage and current variations.

In this research project and this paper, Distance Relay is assumed to operate as a black box, reqardless of its internal structure, to which voltage and current near to their real values has to be applied and its performance has to be evaluated at its input and output contacts.

Obtaining performance characteristics of a relay without applying correct signals to it will lead to unrealistic results. To get closer to the real situation, the effects of following factors on the test results must be taken into account during the test period:

- prefault voltage and current
- fault voltage and current
- transition from prefault situation into post-fault situation
- the effect of load current on fault signals
- the existence of damping DC component in fault current
- the existence of high frequency transition mode.

Since in the proposed algorithm, calculation are based on phasor method, therefore, the transition mode and DC component can be neglected. In the other hand, since the test signals are applied only at the main frequency component (50 Hz) then transition from prefault situation into faulty situation takes place with sudden variation of signals. Fig. 2 illustrates such an event.

Baring in mind that, electromechanical relays due to their inertia and static relays as well as digital relays suppress transition mode in themselves due to low pass filter or signal processing techniques, therefore, distance relays are responsive only to the main components of the applied quantities. That indicates, the proposed test method is valid and can be a suitable reference for interpretation of results of transition test in the similar fault events [6].

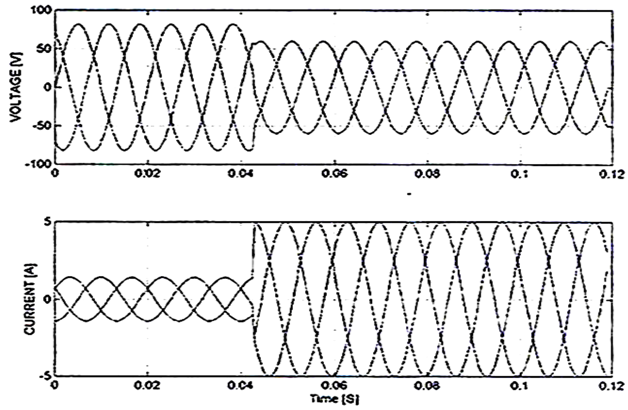

Fig.2 (a) Dynamic test voltage signal,
(b) Dynamic test current signal

3 The Effect of Source Impedance on Distance Relay Performance:

Taking into account the effect of source impedance as a parameter in calculation, is an advantage of dynamic test. The occurrency of performance of distance relay and time of measurement depend upon the minimum voltage which is applied to the relay by voltage transformer at the time of fault occurrence. As it is shown in Fig. 3, this voltage is a function of source and line impedances between point of fault occurrence and the relay. The amount of this voltage depends on the level of short-circuit of network or resistance of the source and the line impedance between the point of fault occurrence and relay, as follows:

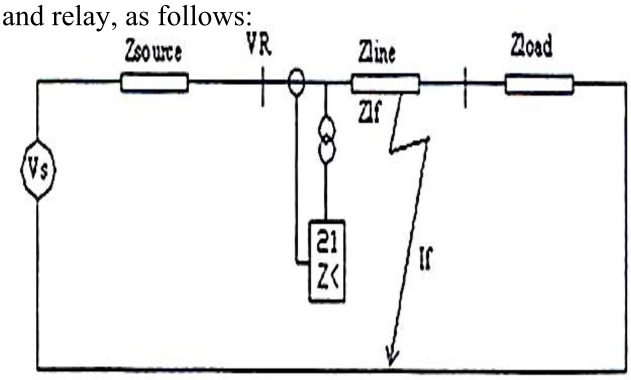

Fig. 3 The network under fault

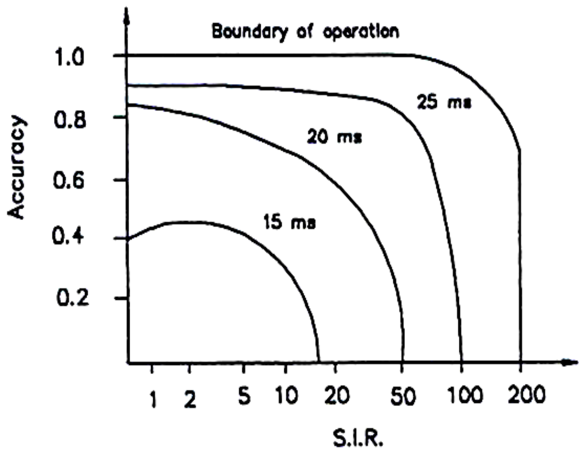

Fig.4 Insochronic Curves

$$Z_{Source} = \frac{U^2}{S_k}$$

(1)

$$where: S_k = short\ circuit\ power$$
$$: U = line\ voltage$$

$$V_R = I_f \times Z_{L_f} = \left[\frac{V_s}{Z_s + Z_{L_f}}\right] \times Z_{Lf} = \frac{V_s}{1 + \frac{Z_s}{Z_{Lf}}} \quad (2)$$

Therefore, applied voltage to the relay depends on the ratio of $\frac{Z_s}{Z_{Lf}}$.

Fig. 4 illustrates isochronic curves of a relay. These curves show the effects of source impedance ratio (SIR) on the performance time of relay according to the place of fault occurrence. As these curves indicate, the stronger the applied signals, the shorter will be the time of operation.

It should be mentioned that, R-X specification curves of certain relays such as cross polarized, is directly related to the source impedance for test of which steady state process of test would not be suitable, therefore, in such a cases considering Z_s in the process of calculation seems necessary.

4 Test Algorithm:

In this method the fault is simulated at a point of the power transmission line and at that point the voltage and current are calculated from the point of view of the relay. The calculations are based on symmetric elements. Fig. 5 illustrates the equivalent circuit.

The following information about the above mentioned circuit have to be completed by the user for calculation of fault:

- Positive sequence of line impedance up to the point of fault occurrence: Z_{L1}
- Zero sequence of line impedance up to the point of fault occurrence: Z_{L0}
- Positive sequence of source impedance : Z_{S1}
- Zero sequence of source impedance: Z_{S0}
- Arc resistance: R_f
- Prefault current: I_{pf}
- Fault type

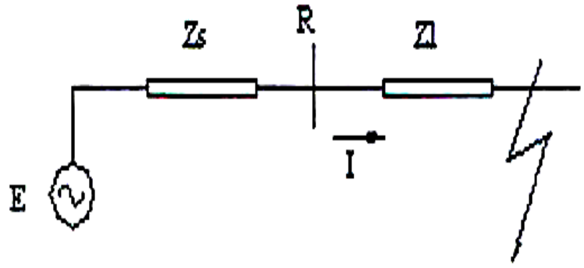

Fig.5 Eequivalent Circuit

In each case, a subroutine is run according to type of fault and faulty phases. The three phases voltages and currents are computed in each subroutine through phases method. An example of calculation for phase "a" to ground fault is given in Fig.6.

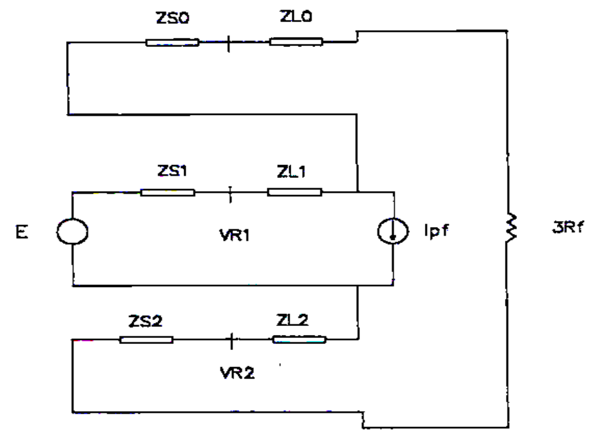

Fig.6 Equivalent circuit for single phase to ground fault

Assuming that positive and negative sequences of impedance are equal and the following ratios are constant:

$$q = \frac{Z_{L0}}{Z_{L1}}, p = \frac{Z_{S0}}{Z_{S1}} \quad (3)$$

and by defining K_i according to the following equations:

$$K_1 = (a - a^2)p - 1 - 2a^2$$
$$K_2 = p - a^2 q - 1 - 2a^2$$
$$K_3 = (1 - a)p - a - 2a \quad (4)$$
$$K_4 = p - aq - a - 2a \quad , a = -\tfrac{1}{2} + j\tfrac{\sqrt{3}}{2}$$

The three phase voltages and currents after fault point are calculated at the point of relay as follows:

$$Den = (2 + p)Z_{S1} + (2 + q)Z_{L1} + 3R_f \quad (5)$$

$$I_A = \frac{3E}{Den} + \frac{(p-1)Z_{S1} + (q-1)Z_{L1} + 3R_f}{Den} I_{pf} \quad (6)$$

$$I_B = a^2 I_{pf} \quad (7)$$

$$I_C = aI_{pf} \quad (8)$$

$$U_A = \frac{(2+q)Z_{L1} + 3R_f}{Den} E + \frac{(p-q)Z_{S1}Z_{L1} - 3Z_{S1}R_f}{Den} Ipf \quad (9)$$

$$U_B = a^2 E + \frac{(1-p)Z_{S1}}{Den} E + \frac{K_1 Z_{S1}^2 + K_2 Z_{S1}Z_{L1} - 3a^2 Z_{S1}R_f}{Den} Ipf \quad (10)$$

$$U_C = aE + \frac{(1-p)Z_{S1}}{Den} E + \frac{K_3 Z_{S1}^2 + K_4 Z_{S1}Z_{L1} - 3aZ_{S1}R_f}{Den} Ipf \quad (11)$$

Afore calculated values for voltages and currents are complex numbers, by calculation of which a complete sinusoidal cycle of each quantity related to the situation of post – fault is calculated and saved as "Faulty Cycle".

The voltage and current prior to the fault also can be calculated at the relay point and a complete sinusoidal cycle of this mode is calculated and saved "Healthy Cycle".

The number of cycle repeatation is determined by the user.

The prefault cycles number are important in memory polarized relay. In this type of relay 20 to 30 cycles of prefault voltage are always saved in the memory to help the relay in detecting the right direction in case of three phase fault occurrence in near distance of which the voltage is zero.

The number of cycles after fault occurrence becomes important in testing the operation time of relay in various zones. As an example for testing the operation time of relay at zone 2 the fault duration time should be more than regular time set for the relay at this region.

5 Data Transferring:

Software interruptions are used to transfer data to the output ports. To synchronize data transferring, interruption of timer should be activated. Therefore, there would be a need for computer timer programming. It should be noticed that, information transferring is on base of real time.

The existing testers have a separate hard ware such as DSP, memory, timer and etc, while in this method the timer and memory of PC are only used and there is no need for extra hardware.

At the instant of transition from the prefault mode into fault mode, the interruption counter starts counting the number of interruptions. At any instances digital input traces output contacts of the relay and should it be equal to that of predetermined value then, the test will stop and the number of interruptions will be recorded.

Since the time of occurrence of each trip is constant, the performance duration of relay can be calculated. Fig.7 shows the performance of relay.

At the starting instance of fault, the digital input may be activated and by application of suitable error signal one can evaluate the mode of relay for instance, by applying a fault in second zone and activating transfer trip input, one can investigate the "Permission Under Reach" mode of relay.

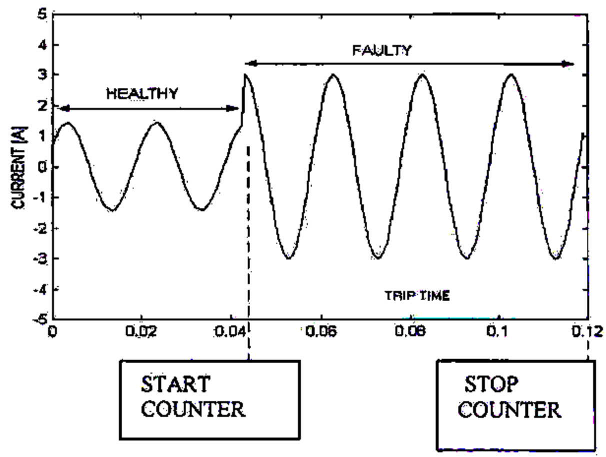

Fig.7 Management of operation time

6 Deduction of Relay Specification:

The point/s at which fault may occur in a line can be determined by changing Z_{L_f} in Eq(2)[3]. The procedure is as such that, at first the test zone/s at impedance plan is/are specified by the user. Then the test points are calculated by dR and dX as follows

$$dR = \frac{R\max - R\min}{20} \quad (12)$$

$$dX = \frac{X\max - X\min}{20} \quad (13)$$

(14)

$$Z_{L(i,k)} = (R\max - idR) + j(X\max - kdX)$$
$$i = 0,1,.......,19$$
$$k = 0,1,.......,19$$

Note:

It should be noted that, as it is illustrated in Fig.8 the test zone includes mini and maxi of R and X.
As it can be deduced from the above Eqs, there are 400 test points in the test zone. By computing the characteristic of Z_L at each test point, with the help of Eq.5 to Eq.11, the test will be continued up to the end of relay performance duration. This measured time as well as characteristic computed ($Z_{L(i,k)}$) are saved as the specification of a test point.

The distance relays are normally "self reset". So their output contacts will return to its normal position by cancellation of fault. The time interval between two successive test points is at least 20 m second. Fig.9 shows the results of test of a rectangular specification relay for a single phase to ground fault with Z_s=1.8 Ω and $I_{prefault}$=1A.

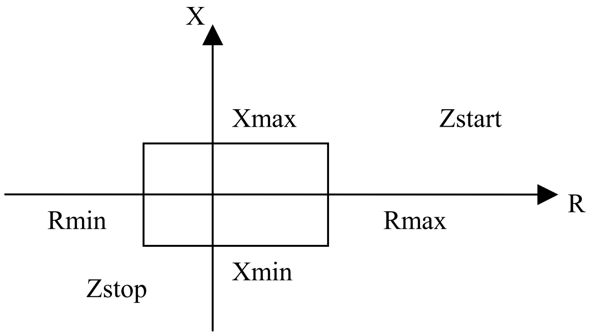

Fig.8 Test ranges

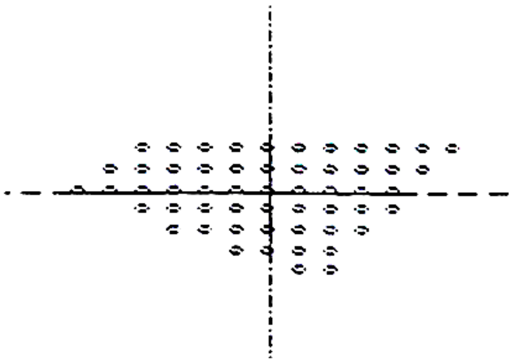

Fig.9 Result of test relay characteristic

To present the result numerically, a format such as table 1 is to be designed. Table 1 is giving a part of test report of the relay.

Table 1 A sample of test result report

R	X	Trip Time	Note
5	-1	700	Out of Zone3
4.5	-1	700	Out of Zone3
4	-1	602	Zone 3
3.5	-1	602	Zone 3
3	-1	600	Zone 3
2.5	-1	403	Zone 2
2	-1	400	Zone 2
1.5	-1	26	Zone 1
1	-1	26	Zone 1
0.5	-1	25	Zone 1
0	-1	25	Zone 1
-0.5	-1	25	Zone 1
-1	-1	26	Zone 1
-1.5	-1	26	Zone 1
-2	-1	401	Zone 2
-2.5	-1	405	Zone 2
-3	-1	603	Zone 3

7 Conclusion:

In this paper a new approach to dynamic test of distance relay has been introduced. This method can also be used for deducting the specification curve of relay as a base for evaluating its real specification which is reported in the catalogs. Sweeping the impedance surface performance of any kind of relay can be evaluated. This method can also be applied to relays whose specifications are off - set.

This method can also be used to evaluate relay performance in different modes of fault, different SIRs when the prefault conditions are changing, and unknown relay under specific conditions. This method can be a valid reference for evaluating the results of transition test in similar fault occurances.

Acknowledgment:

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8 References:

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