Application Note

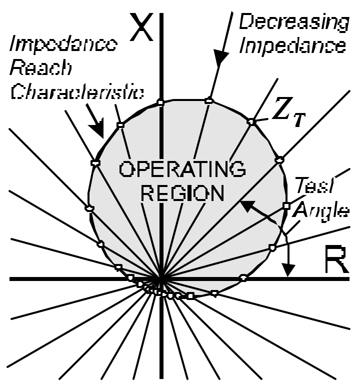
REL 512
AN-40L-99

Substation Automation and Protection Division

Overreaching of the Impedance Characteristic Using Automated Testing

Introduction

A common function of the automated test set is the development of the impedance reach characteristic defined in the impedance plane. The relay reach characteristic is tested with the applied test quantities of V_T and I_T. One method is to set the phase angle of the applied test current, I_T, at a specified value referenced to the test voltage, V_T. I_T magnitude is increased, from some small value that would have the impedance outside of the operating region, until relay operation occurs. V_T and I_T are recorded and the impedance, Z_T, is computed and compared to the expected results based on the relay settings and operating characteristics. This process is repeated for different angles of I_T until the characteristic is adequately defined. Figure 1 is an illustration of how the characteristic is determined for impedances presented to the relay from 0^0 to 360^0.



$$Z_T = V_T / I_T$$

V_T = Applied test voltage
I_T = Applied test current
Z_T = Impedance at operation

Figure 1 - Testing the Impedance Characteristic

The test results for an adequately designed impedance element will fall on or be very near the predicted curve. When testing the zone-1 impedance units of the REL 512, overreach errors as shown in Figure 2 have be observed while testing with a number of different manufacturers' test sets. This application note will show the error is the result of an instantaneous change of current that occurs in the automated test process and recommend testing solutions.

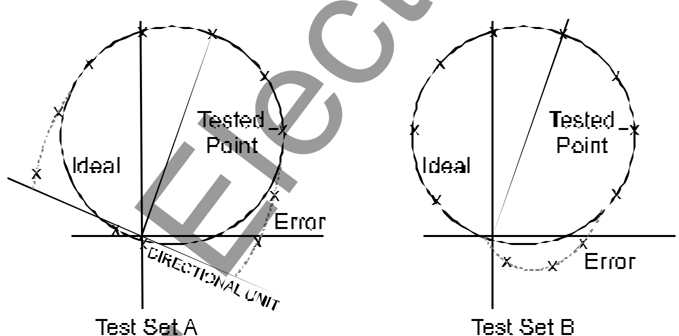


Figure 2 - Apparent Impedance Characteristic Error Due To Pulse Testing

Mho-circle Error

The previous generation microprocessor relay such as the REL 301/2, for example, operates using Fourier transform methods using sampled data collected only after the fault inception transient. This is adequate for 1.5 to 2 cycle relay operations. In order to achieve high speed or sub-cycle operation, the REL 512 operates based on computed torque produced by sampled data that includes the fault transient. The response of the REL 512 to this fault inception transient is accurate when operating on the power system where current (and voltage) transient responses are a function of system inductance, capacitance and resistance. Extensive Model Power System testing and accurate EMTP digital system simulation models have verified this. Test set pre-fault to fault state switching transients which are step changes in current are not representative of real system operations. These switching transients can adversely affect the mho-impedance circle characteristic test results. The units can overreach the expected impedance test values for step-changed (pulsed) test currents applied well off the maximum torque angle usually at high values of test current. The result is an undesired momentary operation lasting less than 1/4 cycle after test current application. Because of the momentary nature only zone-1 tripping is affected. Additional discussion is provided under State Switching Analysis.

Solutions

The REL 512 has fault-transient logic that blocks operation during the first 3/8 cycle after fault inception. Fault inception is defined by a change in both current and voltage. This would prevent relay tripping even if under some remote circumstance a zone-1 impedance unit momentarily operated. Accurate results can be obtained if during the ‘off’ or ‘prefault’ state normal voltages and currents are applied, and during the ‘pulse’ or ‘fault’ state both voltage and currents are switched to the fault quantities.

Accurate impedance characteristic test results can also be obtained using a number of other methods. The first is by ramping the current up in small increments while maintaining constant test voltages. The small changes in current will not affect the impedance unit operation. This requires disabling the zones not being tested.

A second alternate method is to use the pulse method with a constant voltage and use a combination of modified mho characteristic tests, complemented with dynamic testing. Testing the forward looking zone impedance characteristics is limited to the line angle (MTA) setting +/- 60^0 (15^0 to 135^0 for an MTA of 75^0). This provides accurate characteristics in the forward region where relay operations are minimally affected by the pulse transient. These test are complemented with one or more reverse fault dynamic tests which switch from normal operating voltage and current quantities to fault quantities.

A third method is to map (program) the Z1 TRIP signal to a programmable output. The mapping logic requires time and delays operation of the ZONE 1 TRIP through the mapped contact by approximately a quarter of a cycle. Using this method the full 360^0 circle can be tested.

State Switching Analysis

This analysis is provided to show the effect of current change during state switching. Figure 3 shows the results of two cases. Both cases are identical except for the transient time constant, tc, used when switching from the prefault to fault state. The applied test voltages and currents are shown in Table 1.

Table 1 - Transient Current State Switching Tests

State	Pre-fault		AB Fault		Post Fault	
Quantity	Ampl	Phase	Ampl	Phase	Ampl	Phase
Va	40	0	40	0	0	0
Vb	40	240	40	240	0	0
Vc	70	120	70	120	0	0
Ia	0	0	20	80	0	0
Ib	0	0	20	260	0	0
Ic	0	0	0	0	0	0
Time	20 Cycles		5 Cycles		60 Cycles	

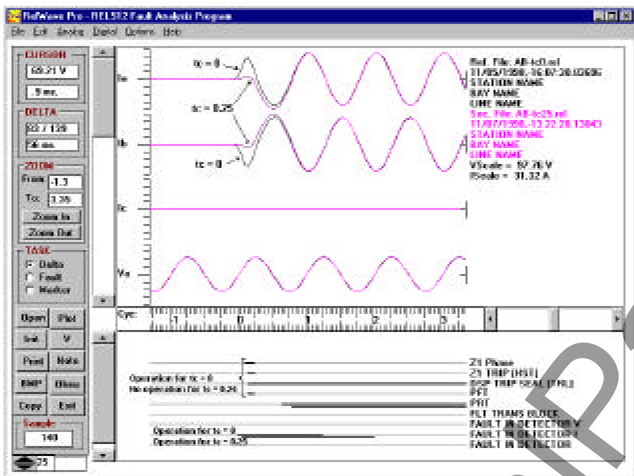


Figure 3 - Tests Using Time Constants of tc = 0.0 and tc = 0.25 Cycle

The test quantities represent the test set quantities being applied for a test pulse while determining the impedance characteristics. The voltages are constant for prefault and fault states while the current switches from zero to the test value. For these cases the applied phase A test current leads phase A voltage by 80^{0} and leads the phase AB fault voltage by 50^{0}. This puts the fault impedance in the fourth quadrant of the of the impedance plot at 310^{0}. As illustrated in Figure 2 of the paper, this is the region that is most susceptible to the undesired test operation.

Figure 3 shows the results of both tests. The upper window shows the analog quantities. The test with tc = 0, which represents the test set, shows the abrupt transient current between states while the test with tc = 0.25 cycle shows a real world transient current with moderate dc offset.

The lower window shows the pertinent measuring unit and logic responses to the two faults. Digital operations for case tc = 0 are shown in black on the light gray line. Digital operations for the case tc = 0.25 cycle are shown below the gray line, Both digital operations are apparent for the signal FAULT IN DETECTOR I. For case tc = 0, the zone-1 phase-to-phase unit, Z1 Phase, momentarily operated. This short operation resulted in the relay tripping as indicated by the logic signals Z1 TRIP and DSP TRIP SEAL. It is also noted that the forward pilot zone and supervising logic, PFT, momentarily operated as well. Correct operations shown for case tc = 0 are FAULT IN DETECTOR I and PRT, the reverse pilot zone and supervising logic. For the case tc = 0.25, there were no incorrect operations. The second, and lower, digital operation lines show operations for this case. The signals PRT and FAULT IN DETECTOR I operated for both cases.

Case tc = 0 was modified to demonstrate relay operation when there is a voltage change at fault inception. The test quantities in Table 2 were used. A time constant of zero was used.

Table 2 - Transient Current and Voltage State Switching Tests

State	Pre-fault		AB Fault		Post Fault	
Quantity	**Ampl**	**Phase**	**Ampl**	**Phase**	**Ampl**	**Phase**
Va	70	0	40	0	0	0
Vb	70	240	40	240	0	0
Vc	70	120	70	120	0	0
Ia	0	0	20	80	0	0
Ib	0	0	20	260	0	0
Ic	0	0	0	0	0	0
Time	20 Cycles		5 Cycles		60 Cycles	

The test results shown in Figure 4 show the momentary operation of the Z1 Phase unit as expected for tc = 0. Also shown operated are the signals FAULT IN DETECTOR V and FLT TRANS BLOCK. No Tripping occurs. The signal FLT TRANS BLOCK is asserted at fault inception with the operation of both FAULT IN DETECTOR V and FAULT IN DETECTOR I and blocks tripping for 0.4 cycle.

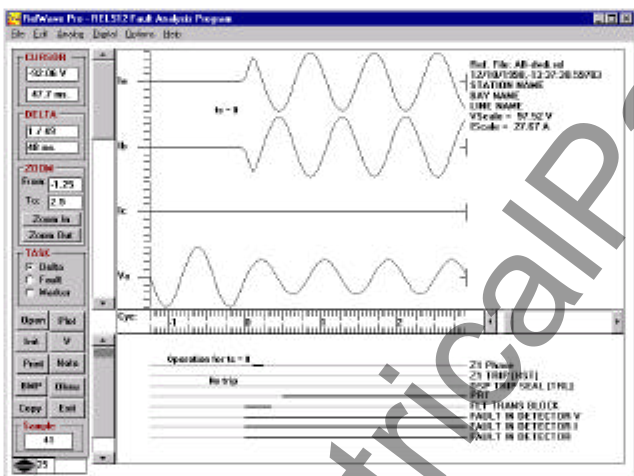


Figure 4 - Test Showing Trip Blocking for Current Time Constant tc = 0

The above tests demonstrate the adverse effect of test set current switching on high-speed relays. The tests also show that including a very small transient time constant (0.25 cycle) effectively eliminated the incorrect momentary operation of the impedance units. Further, trip blocking is effective in blocking this transient condition to allow dynamic testing.

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