Testing Impedance Characteristics

72nd Annual Conference for Relay Engineers, 2019

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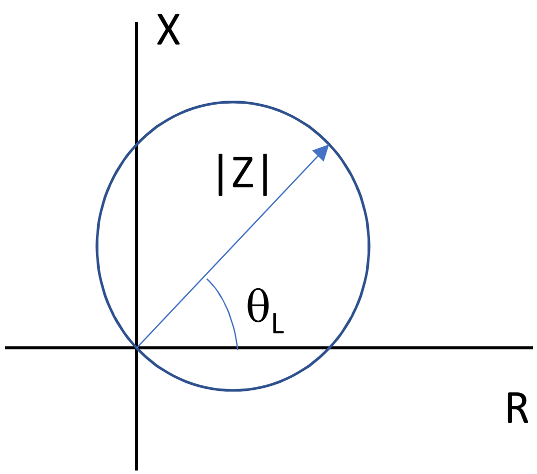
CONTENT

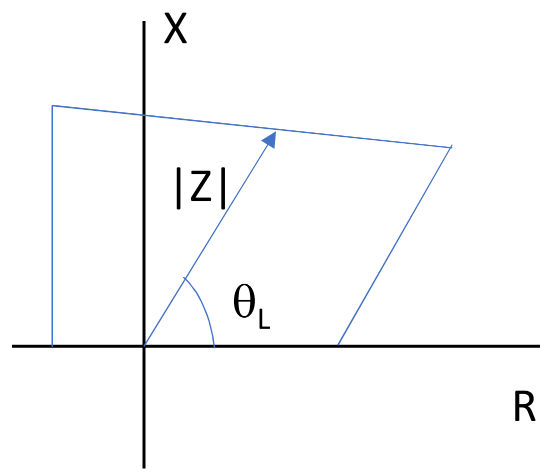
Background & Objectives

Background

- ❖The commissioning of relays before integration with the system and routine test during service life are regulatory requirements.
- ❖This paper emphasizes on the protection function test of two common impedance characteristics, Mho and Quadrilateral used in power systems distance protection.



Mho Characteristics



Quadrilateral Characteristics

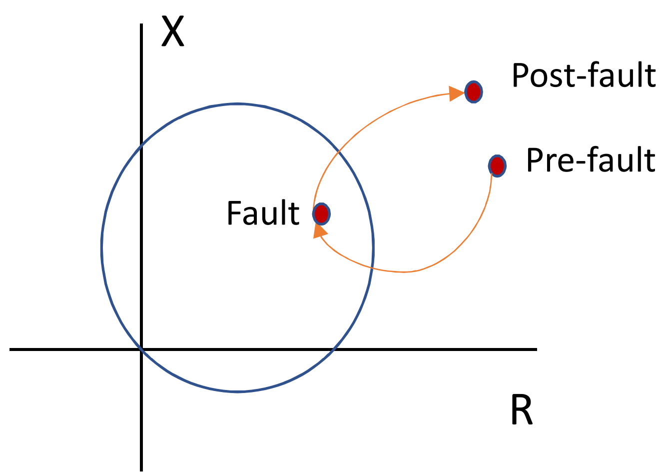
Background & Objectives

Objectives

- ❖Proposing a methodology to create various fault events to trace the operating boundary of impedance characteristic subject to functional and testing hardware constrains.
- ❖The implementation of the methodology using available testing macros or algorithms.
- ❖ Exploring various pros and cons and making recommendations for testing.

Methodology

- The methodology includes applying fault event (in terms of AC quantities) in the inputs of relays and sensing relay output.
- Each fault event comprises of three states, pre-fault, fault, and post-fault/reset.
- Each fault plots a point on R-X plane.

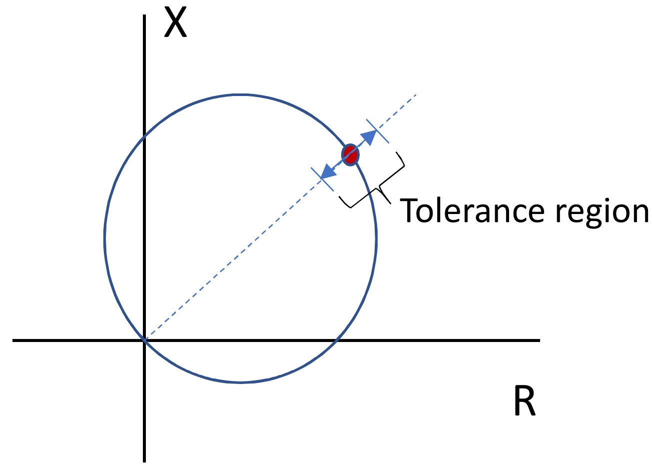


Trajectory of a fault event on R-X plane

Methodology

Test Criteria

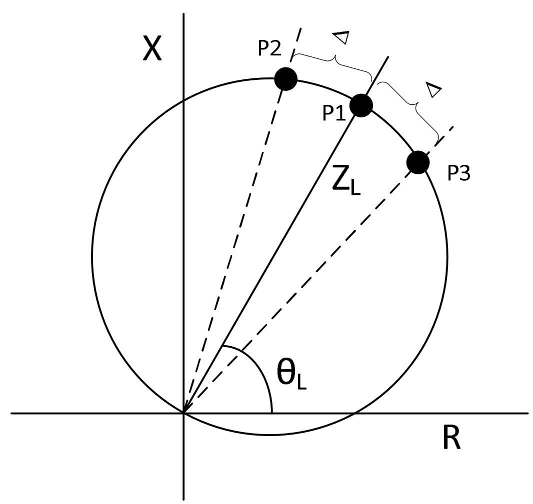
- ❖An ideal relay should operate for a point inside of the operating boundary and should block the operation for a point outside of that boundary.
- ❖However, a practical relay has the tolerance margin due to hardware's performance precision.
- ❖The performance of the relay should be evaluated within the range of tolerance defined by relay manufacturer.
- ❖The test compares the theoretical expected value with the experimental value obtained to verify that the value is within the tolerance levels.



Methodology

Selection of Test Points

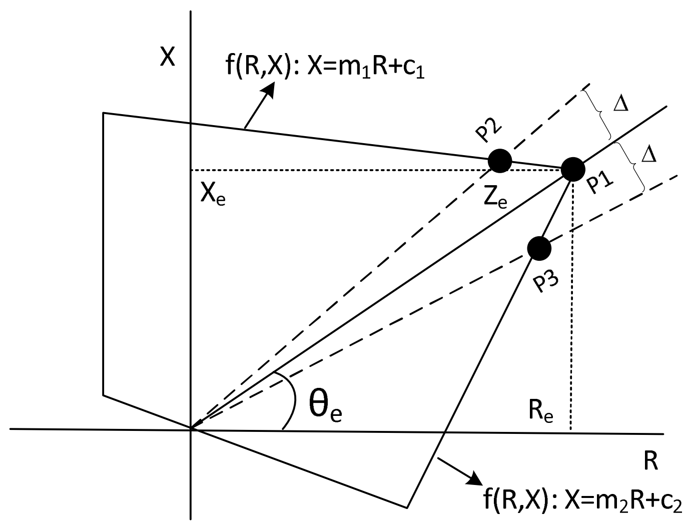
- At least three points should be tested to assess the performance of a non-linear characteristic. For Mho characteristic, the first test point is at maximum torque angle and other two points are selected at two sides of maximum torque angle as illustrated in Figures below.



Methodology

Selection of Test Points

- The impedance function is more exposed to fail at the sharp edges of the operating curve due to overlapped tolerance area. That is why; the first test point is selected at the edge to ensure the correct performance of Quadrilateral characteristic as shown in Figure below. Other two points are nominated by one from each side of the edge



Methodology

Calculations & Conditions

The test current and voltage quantities are calculated based on the following test conditions:

1) Built-in element enable-disable option in the relay.
2) Three-phase voltage is applied for all three states.
3) Pre-fault and post-fault currents are injected in three phases.
4) Fault current is injected only in the selected phases for phase element tests.
5) Fault current is injected only in one phase for ground element tests.
6) Voltage drops only on faulted phases.

Methodology

Calculations & Conditions

Quantities	Default Value	Range
Phase current	Nominal load current	0 to nominal load current
Phase voltage	Rated voltage	-

Pre-fault

Quantities	Default Value	Range
Phase current	0	0 to nominal load current
Phase voltage	0	-

Post-fault

Methodology

Calculations & Constraints

Fault

$$Z = \frac{V_p}{(1+k)I_p} = \frac{|V_p|}{|(1+k)I_p|}\angle\theta \qquad (phase - ground\ fault)$$

$$Z = \frac{V_{pp}}{2I_p} = \frac{|V_{pp}|}{2|I_p|}\angle\theta \qquad (phase - phase\ fault)$$

$$Z = \frac{V_p}{I_p} = \frac{|V_p|}{|I_p|}\angle\theta \qquad (3 - phase\ fault)$$

Known parameters: Z, θ

Unknown parameters: $|V_p|$, $|I_p|$

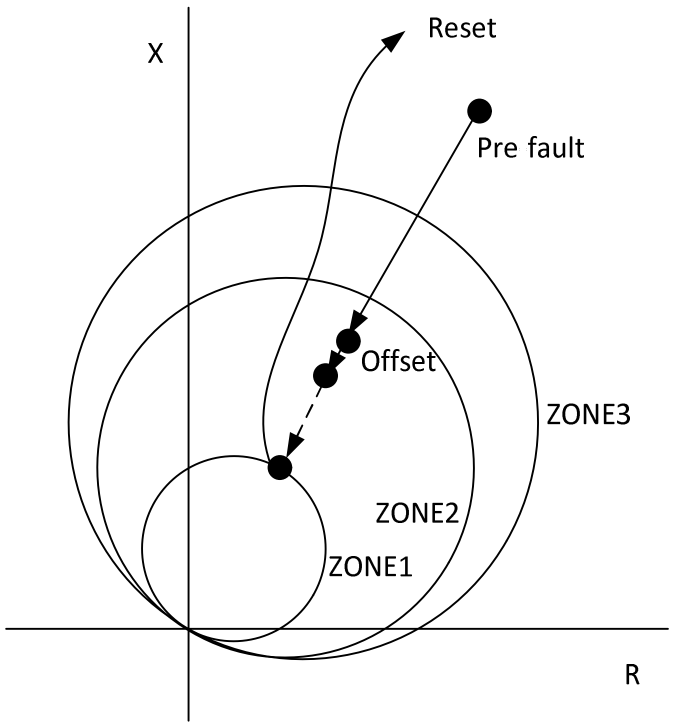
In this paper, the expected fault current (test current) magnitude is assumed within given constraints to calculate the fault voltage for the sake of mathematical simplicity.

Methodology

Constraints & Challenges

- When the impedance element is supervised by the fault current magnitude then the impedance element is only picked up if the fault current is greater than a specific threshold value.
- The maximum possible value of the fault current depends on the capacity of the Power System Simulator used to simulate the fault event.
- The practical fault voltage must be smaller than the rated phase voltage. According to Equations (6-8), the value of the fault voltage depends on the fault current magnitude for a given test point. Therefore, the fault current should be selected within a range so that the fault voltage satisfies the constraint.
- The ground impedance element is supervised by directional conditions described in [2, 4]. The values of the fault current and the fault voltage should be chosen to satisfy the conditions of ground directionality.

Implementation

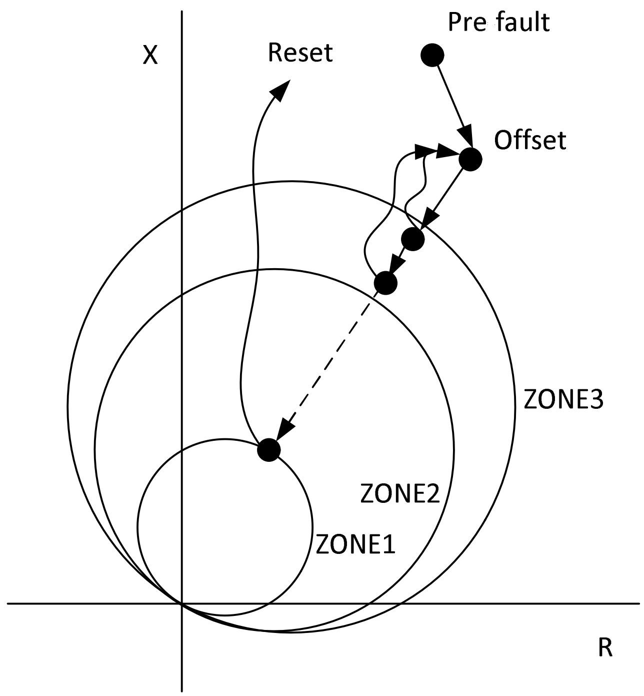


Parameters Setting

Offset Current	**50-95% of the Minimum Expected Current of selected test points**
Offset Duration	≥5 cycle
Delta Current	>0.0 A (higher value requires higher delta time)
Delta Time	≤(Time delay + 5) cycle
Current Limit	120% of Maximum Expected Current of the selected test points

Linear Ramp (LR) Algorithm

Implementation



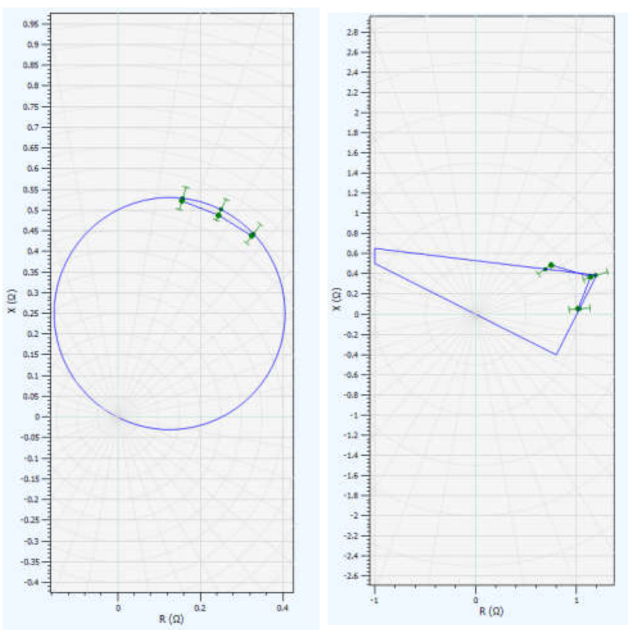
Parameters Setting

Offset Current	**Load current**
Offset Duration	≥5 cycle
Initial Pulse Current	90-95% of the Minimum Expected Current of selected test points
Pulse Duration	(Time delay + 5) cycle
Wait Time	≥5 cycle
Delta Current	>0.0 A (higher value requires higher delta time)
Current Limit	120% of Maximum Expected Current of the selected test points

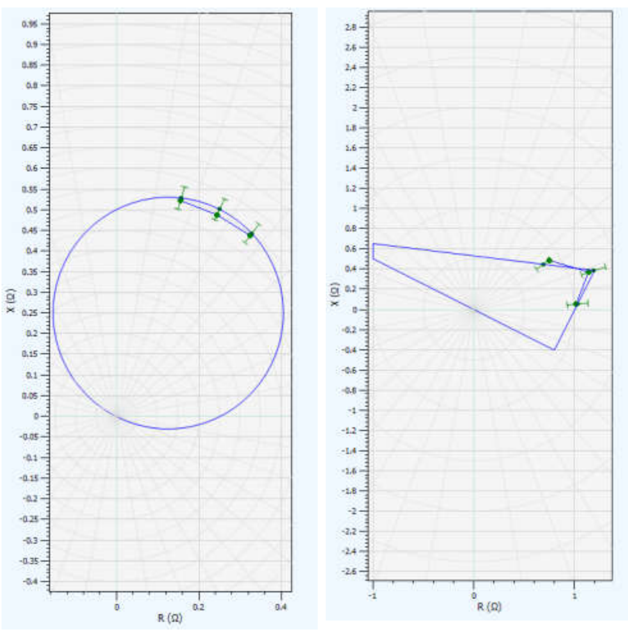
Pulsed Linear Ramp (PLR) Algorithm

Results & Discussion

$OUT\ X = Z1T$ $(Single - function)$



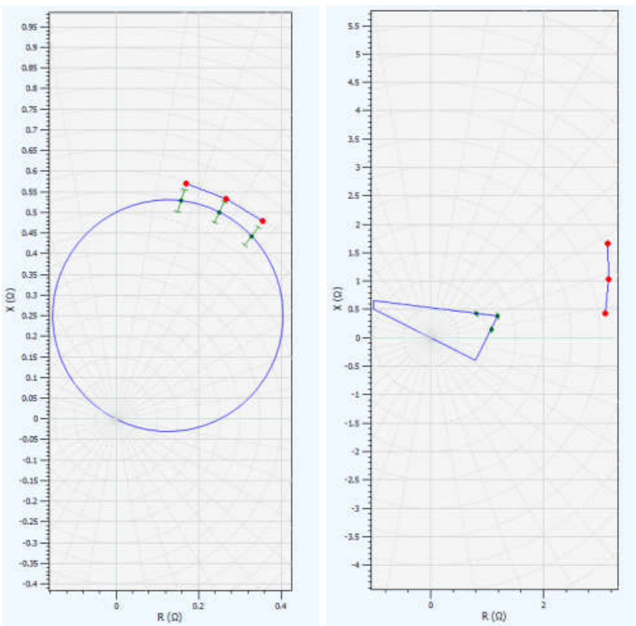
LR



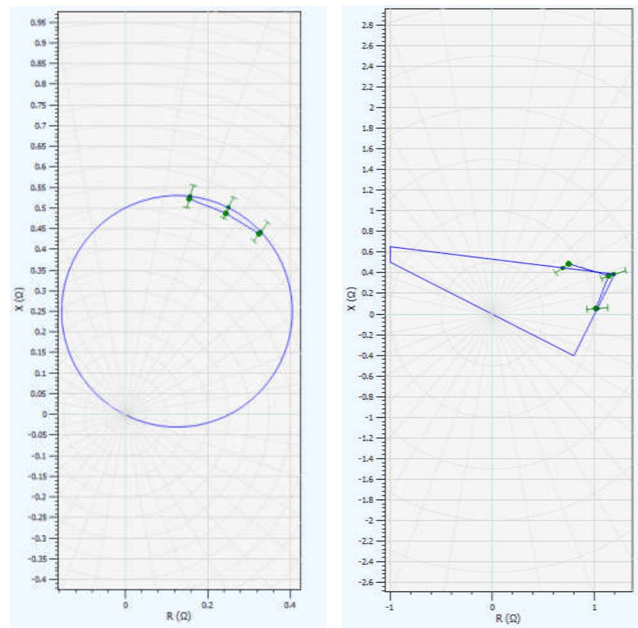
PLR

Results & Discussion

$OUT\ X = Z1T\ OR\ Z2T\ OR\ Z3T$ $(Multi - function)$



LR



PLR

CONCLUDING REMARKS

- The paper proposes a methodology to test impedance operating characteristics at multi-points of its boundary.
- The article also explores two search algorithms to implement the methodology in Power System Test Simulator.
- The analysis suggests that Pulsed Linear Ramp (PLR) algorithm is much appropriate one to implement the proposed impedance test methodology while Linear Ramp (LR) can be limitedly applied for single-element relay output test.
- The performance of the proposed methodology implemented in LR algorithm is vastly depends on the tuning of the test parameters such as Offset current, Delta current, and Delta time.

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THANK YOU! ☺