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A New Model of Numerical MHO Distance Relay Associated with Power Swing Detector

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Abstract: In conventional transmission line protection, a distance relay is used to provide the primary as well as backup protection. The voltage and current phasors measurement needed by the distance relay for determining the impedance may be affected by the power disturbances such as power swing. Consequently, this power swing may cause mal-operation of Zone three distance relays which in turn may affect on the reliability of the whole protective scheme. Many power swing blocking functions (PSB) have been developed to mitigate these effects.

In this paper, a new model of Mho distance relay with dual-quadrilateral power swing detection characteristic has been developed and implemented first in PC using LabVIEW, then tested using Power System Simulink Model under different faults and power swing conditions. Finally, the relay prototype has been realized using acquisition card NI USB-6009, which acquires real-time signals of the currents and the voltages, processes them digitally and outputs tripping or blocking signal to the circuit breaker. The obtained results show that the relay provides good discrimination between a fault and power swing condition.

Keywords: Mho distance protection, power swing, dual-quadrilateral characteristic, Labview, myDaQ board NI USB-6009.

6. INTRODUCTION

Power grid protection role is to make the power system including transmission and distribution network as safe as possible from the effects of equipment failures and events that place it at risk. When the faults occur in such power grid, protection schemes are designed to isolate faulted part, and leave the healthy parts of the system connected in order to ensure the continuity of the power supply [4, 8]. Power system disturbances cause oscillations in machine rotor angles that can result in severe power flow swings. Depending on the severity of the disturbance and the actions of power system controls, the system may remain stable or lose synchronism. Large power swings may affect on transmission line relays and protection scheme in various ways that can further aggravate the power system disturbance and cause major power outages or blackouts.

Many techniques called power swing blocking (PSB) functions are developed in modern numerical distance relays to prevent unwanted distance relay operation during power swings. One of the useful PSB function is the dual-quadrilateral characteristics that is based on the measurement of the time it takes the positive-sequence impedance to cross the two blinders [6].

This paper proposes a new design model of mho distance relay with dual-quadrilateral power swing detection characteristic based on PC associated with myDaQ board NI USB-6009 using LabVIEW as software development tool.

7. THEORETICAL BACKGROUND

2.1 Mho Distance Relay Modeling:

Distance relay may be used in the power grid protection. The basic principle governing the operation of a distance relay is the ratio of the voltage **V** to the current **I** at the relaying point as shown in Fig.1. The ratio (V/I) represents the measured impedance **Z** of the faulty line between the relay location and the point of fault occurrence. Then, the measured impedance is compared to the set impedance, and if this **Z** is within the reach of the relay then it operates [3, 5].

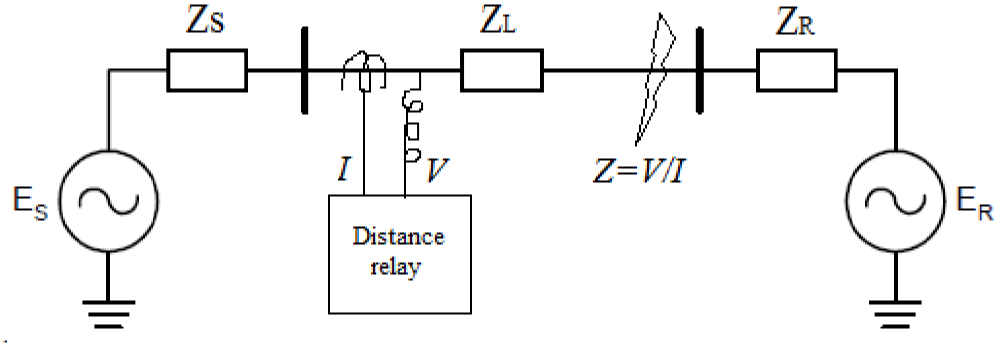


Fig 1. typical single line AC connection of a protective distance relay.

Distance relay can be implemented through the use of phase comparators of two input quantities S_1 and S_2 [1, 2, 9].The output of a phase comparator operates if the following condition is satisfied

$$-90° \le \theta_{S1} - \theta_{S2} \le 90° \qquad (1)$$

The signals S_1 and S_2 that may be as input to the phase comparator are in the following form:

$$S_1 = -V_r\angle 0° + Z_R\angle\theta_z \,.I_r\angle -\varphi_r \qquad (2)$$

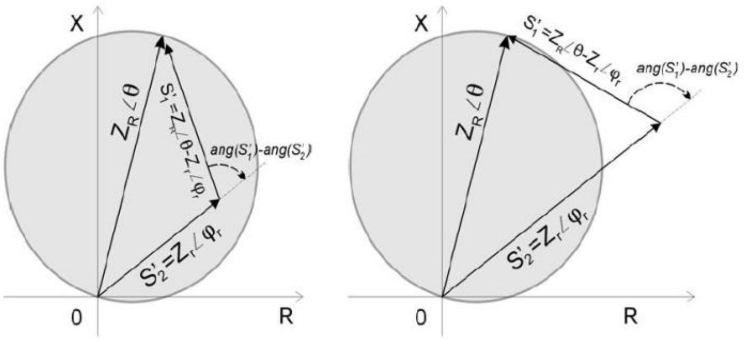
$$S_2 = V_r\angle 0° \qquad (3)$$

Dividing these equations by the line current $Ir\angle -\varphi r$ gives the following equations:

$$S'_1 = -Z_r\angle\varphi r + Z_R\angle\theta z \qquad (4)$$

$$S'_2 = Z_r\angle\varphi_r \qquad (5)$$

As seen in Fig.2, the impedances S'_1 and S'_2 are placed in the extremes of the constant $Z_R\angle\theta_z$ impedance. When the system impedance $Z_r\angle\varphi_r$ is inside the operating characteristic, as shown on Fig (2 (a)), the angle between S'_1 and S'_2 fulfills equation (1) and the relay operates. In Fig. (2(b)) is shown the case of $Ir\angle\varphi r$ lying outside the operating characteristic. Now, the angle between S'_1 and S'_2 is outside the range specified in Equation (1), and the relay does not operate. The constant parameter $Z_R\angle\theta z$ marks the diameter of the circular characteristic that passes through the origin.



a) Operating condition

b) Non-operating condition

Fig 2. Definition of the mho characteristic phase comparator

2.2 Dual-quadrilateral Power Swing Detection Characteristic:

Dual-quadrilateral characteristic for detecting power swing on a transmission system is shown in Fig.3. After crossing the outer blinder the Z_1 impedance, a timer is started. A power swing is detected when the measured time is longer than a set time delay [6, 7].

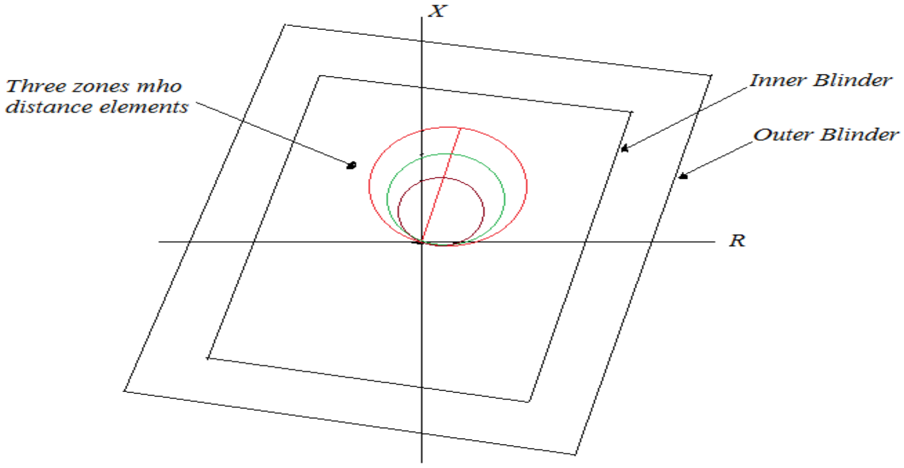


Fig.3 Dual-quadrilateral power swing detection characteristic

Setting the dual-quadrilateral characteristic can be investigated by following steps:

a. calculate the system equivalents by calculating the correct impedances (Z_S, Z_L, Z_R of Fig.1).

b. set the power swing slip rate (between 4 and 7 Hz).

c. set the inner and outer blinders, Two methods can be used to determine the blinder settings:

c.1. select the inner blinder (INBR) setting to be outside of the furthest reaching distance element that is supervised by the PSB element. Select the outer blinder (OTBR) setting to be inside maximum load flow. Both the inner and outer blinder settings should be set with adequate margin. Use a margin of about 20 percent to ensure secure operation.

c.2. select the power angle for the inner and outer blinders using the system equivalent impedance data as shown in Fig.4. Select the inner and outer blinder power angles to allow adequate margins as stated in Method 1.

$$ANGIR = 2 \cdot \operatorname{atan}\left(\frac{|ZT|}{2 \cdot INBR}\right) \tag{6}$$

$$ANGOR = 2 \cdot \operatorname{atan}\left(\frac{|ZT|}{2 \cdot OTBR}\right) \quad \text{where ZT=Z1S+Z1L+Z1R} \tag{7}$$

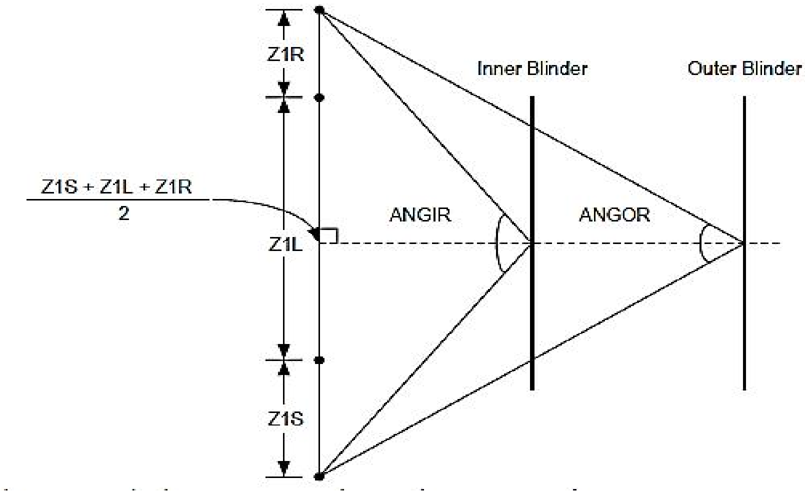


Fig 4.Equivalent Source Angles during Power Swing

d. calculate the PSB time delay as follows:

$$PSBD = \frac{(ANGIR-ANGOR)\cdot F_{nom}}{360\cdot SlipF} \qquad (8)$$

Where: F_{nom} is the system nominal frequency in Hz,
Slip F is the power swing slip rate in Hz,

e. set the ''bottom'' and ''top'' of power swing characteristic. It is recommended to be two or three the maximum distance element reach.

8. RELAY MODELING AND IMPLEMENTATION

The model of the proposed Mho relay is presented and summarized in the flowchart illustrated in Fig.5.

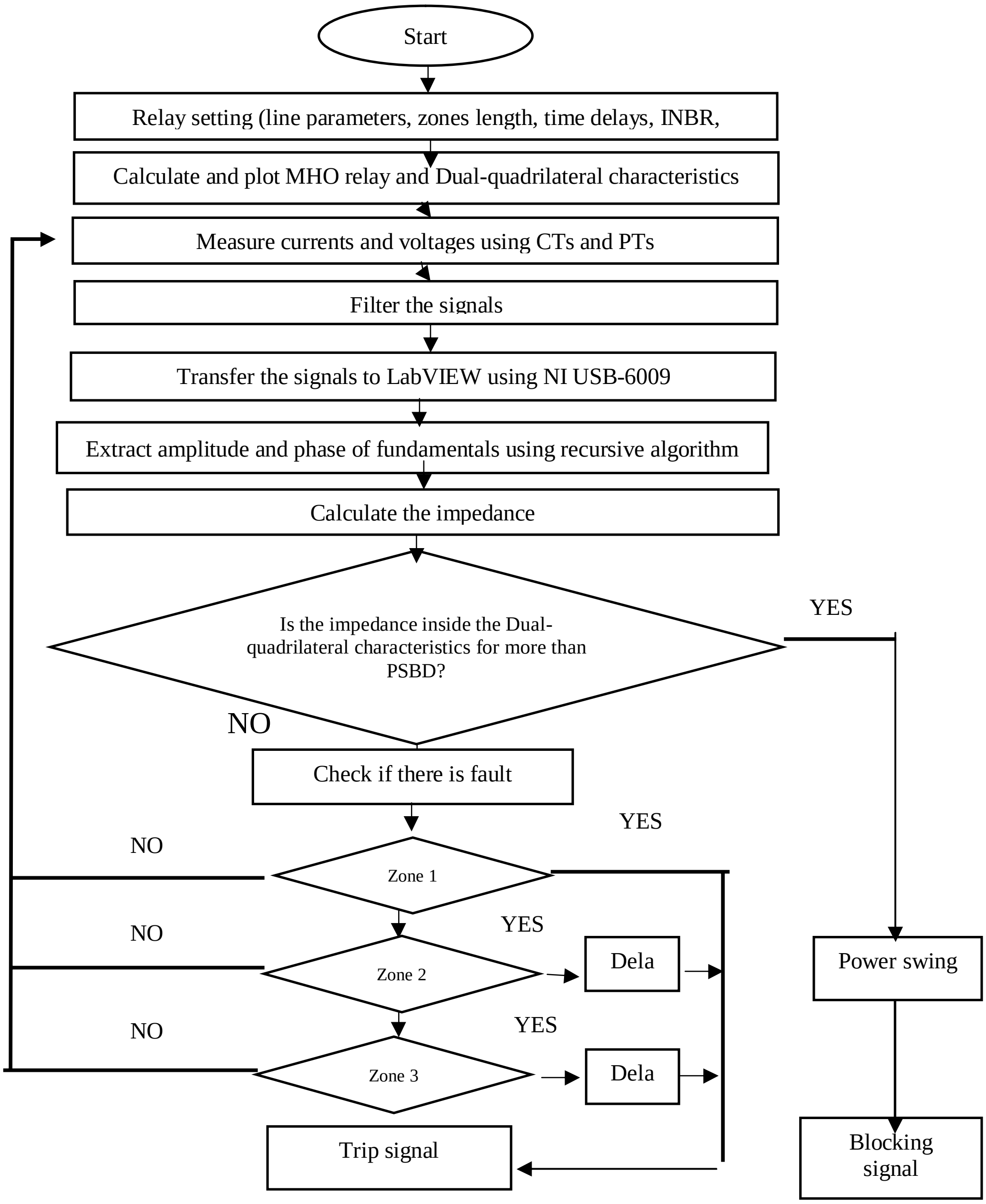


Fig 5. A Flowchart of Mho relay algorithm

The proposed protection system model designing methodology as shown in Fig.6 consists of two major parts: Software and Hardware.

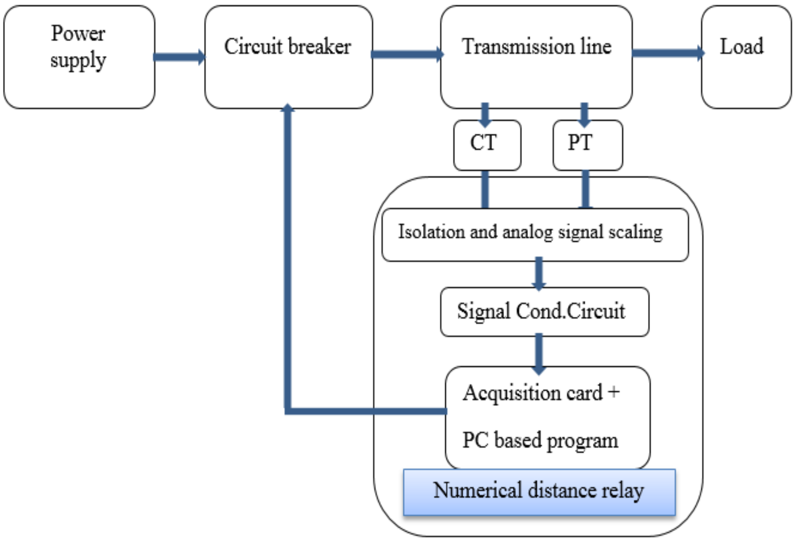


Fig 6. The general block diagram of the proposed protection scheme.

A.Software Part

LabVIEW is used as software tool development, where we can use a relay for multiple zones using only one software environment with advanced built-in analysis and signal processing libraries. The relay and transmission line characteristics are introduced as inputs. The system can monitor the characteristics of the Mho distance relay and the dual-quadrilateral characteristic as well as the impedance trajectory in real time using a waveform graph in the LabVIEW front panel.

B.Hardware Part

The hardware part of the proposed Mho distance relay consists of:

- Isolation and analog signal scaling: this circuit transforms currents and voltages of the power system to low safe values .It consists of:
    - Three potential transformers,
    - Three current transformers.
- Signal conditioning circuit: the measured values that come from CT and PT in analog forms are passed through an anti-aliasing filter amplifier (low pass filter).
- NI USB-6009: Sample and hold circuits and analog multiplexed are used to sample the three different signals supplied by instrument transformers at the same time. The sampled signals are converted into digital form.
- PC: these digital signals are fed from data acquisition board to the PC where they will be processed and taken as input in the developed Mho relay in LabVIEW.

9. TESTING AND RESULTS

To validate the relay model that has been developed in LabVIEW. SIMULINK power system model is used, which is based on a simplified two-generator system (Fig.1), under several faults and power swing conditions.

The parameters of the SIMULINK power system model and the settings of the relay model are mentioned in table 1.

- Case one: Three phase fault

A three phase fault is simulated at zone one, the circuit breaker trips instantaneously and a three phase (ABC) fault is indicated on zone one at a distance of 70.097 Km (Fig.7).

- Case two: Phase to phase fault

A Phase to phase fault is simulated at zone two, the circuit breaker trips after 0.2 s, and a phase to phase (AB) fault is indicated on zone two at a distance of 110.003 Km(Fig.8).

- Case Three: Phase to ground fault

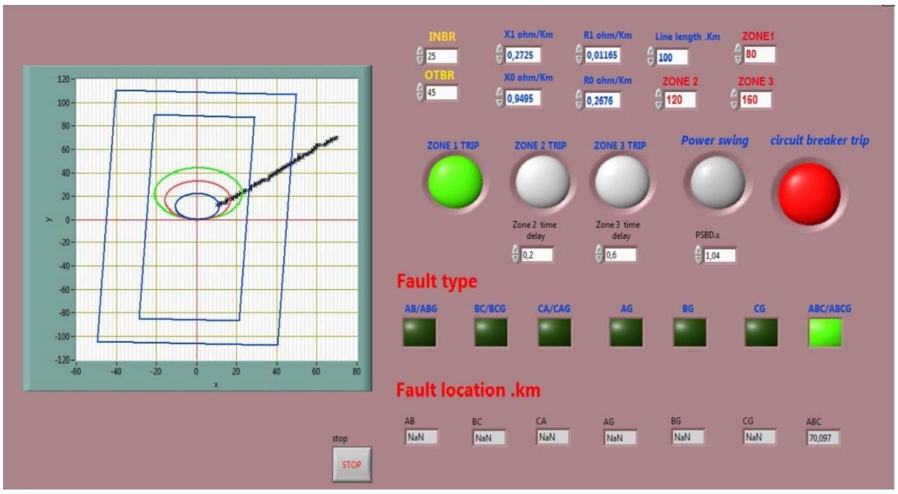
A Phase to ground fault is simulated at zone three, the circuit breaker trips after 0.6 s, and a phase to ground (AG) fault is indicated on zone three at a distance of 140.02 Km(Fig.9).

- Case Four: Power swing

In this case, a power swing is simulated, the power swing is indicated because after the outer blinder crosses the Z1 impedance, a timer is started and the interval of time before the inner blinder is reached is more than 1.04 s, and in this case the circuit breaker is blocked (Fig.10).

Table 1. Power system data and relay setting

Parameters	Value		
Line length	100 km	Relay settings	
Voltage	220 KV	INBR	25 Ohm
Frequency	50 Hz	OTBR	45 Ohm
Line resistance R1	0.01165 Ohm/Km	PSBD	1.04 s
Line resistance R0	0.2676 Ohm/Km	Zone 1	80% instantaneos
Line reactance X1	0.2725 Ohm/Km	Zone 2	120% 0.2 s
Line reactance X0	0.9495 Ohm/Km	Zone 3	160% 0.6 s
Z1S	1.2 + j29.4 Ohm	Z1R	0.6 + j10.4 Ohm



INBR 25
OTBR 45
X1 ohm/Km 0,2725
X0 ohm/Km 0,9495
R1 ohm/Km 0,01165
R0 ohm/Km 0,2676
Line length .Km 100
ZONE1 80
ZONE 2 120
ZONE 3 160
Zone 2 time delay 0,2
Zone 3 time delay 0,6
PSBD.s 1,04
AB NaN
BC NaN
CA NaN
AG NaN
BG NaN
CG NaN
ABC 70,097

Fig 7. Three phases fault ABC at a distance of 70Km

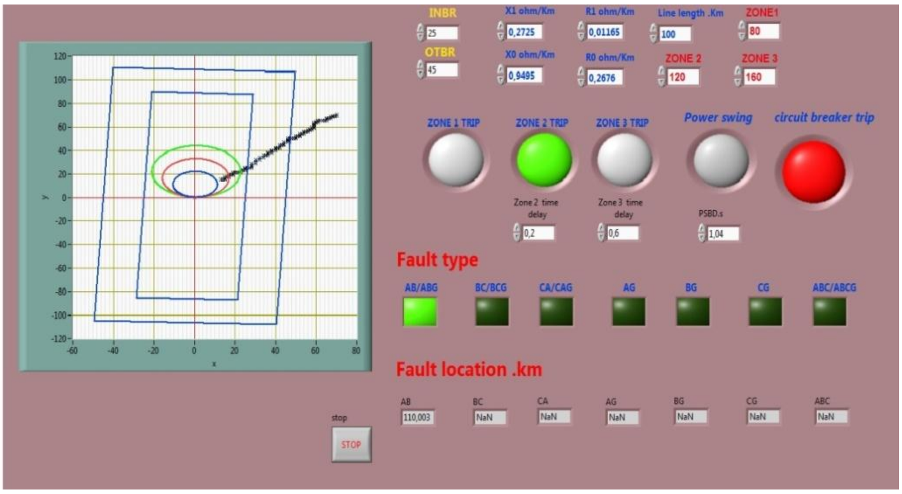

INBR 25
OTBR 45
X1 ohm/Km 0,2725
X0 ohm/Km 0,9495
R1 ohm/Km 0,01165
R0 ohm/Km 0,2676
Line length .Km 100
ZONE1 80
ZONE 2 120
ZONE 3 160
Zone 2 time delay 0,2
Zone 3 time delay 0,6
PSBD.s 1,04
AB 110,003
BC NaN
CA NaN
AG NaN
BG NaN
CG NaN
ABC NaN

Fig 8. Phase to phase fault at a distance of 110Km

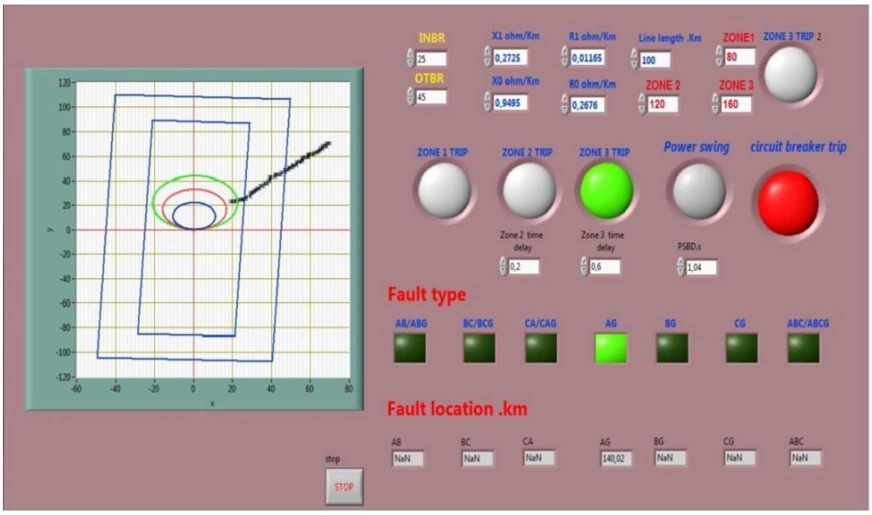

INBR 25
OTBR 45
X1 ohm/Km 0,2725
X0 ohm/Km 0,9495
R1 ohm/Km 0,01165
R0 ohm/Km 0,2676
Line length .Km 100
ZONE1 80
ZONE 2 120
ZONE 3 160
Zone 2 time delay 0,2
Zone 3 time delay 0,6
PSBD.s 1,04
AB NaN
BC NaN
CA NaN
AG 140,02
BG NaN
CG NaN
ABC NaN

Fig 9. Phase to ground fault at a distance of 140Km

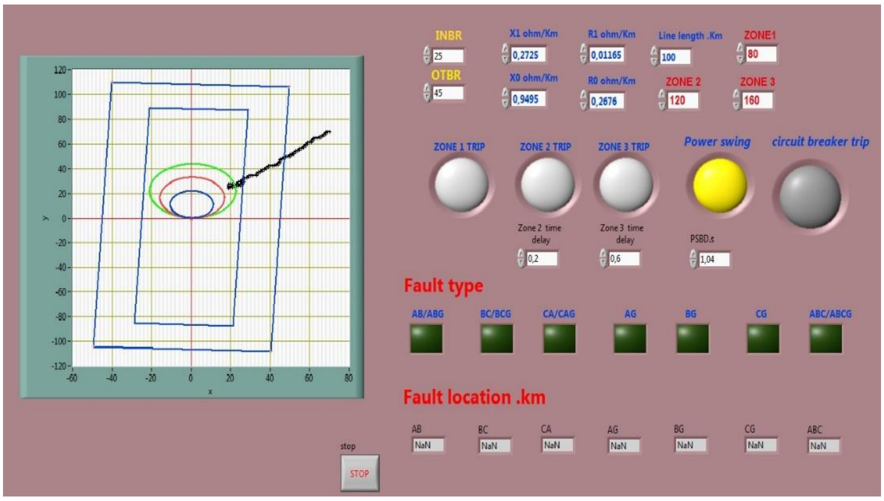

INBR 25
OTBR 45
X1 ohm/Km 0,2725
X0 ohm/Km 0,9495
R1 ohm/Km 0,01165
R0 ohm/Km 0,2676
Line length .Km 100
ZONE1 80
ZONE 2 120
ZONE 3 160
Zone 2 time delay 0,2
Zone 3 time delay 0,6
PSBD.s 1,04
AB NaN
BC NaN
CA NaN
AG NaN
BG NaN
CG NaN
ABC NaN

Fig 10. Power swing condition

10. CONCLUSION

In this paper, a new design model of Mho distance relay with dual-quadrilateral power swing detection characteristic has been successfully developed using LabVIEW software. By testing the behavior of the developed relay model under different faults and power swing conditions, the relay model has been able to detect a power swing condition and send a block signal to the circuit breaker. It has been able also to detect all the fault types and send a trip signal to circuit breaker. Besides, from perspective impedance calculations, the relay model has the ability of indicating the correct zone of operation in all cases. The relay identifiers the fault locations as expected, as the fault location is changed, the measured impedance changes consequently.
Moreover, it can be concluded that this proposed scheme has the following advantages:
Firstly, the relay provides good discrimination between a real fault and power swing condition.
Secondly, this complex protection scheme can easily be implemented on PC using LabVIEW.
Finally, this project is suitable for education for showing to the power engineering students the Mho distance relay principle of operation as well as the power swing detection techniques.

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