MODELING OF NUMERICAL DIFFERENTIAL RELAY

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Abstract: This paper is based on modeling of different types of digital differential relays with different fault conditions. For fault accrue in secondary winding of transformer. In simulation there different types of transformers are used. My dissertation also shows the conventional difference between two relays which behavior is changed with changing in source. As known that relay is a input switch and its all operating condition depend on transformer and load. In this paper firstly I create a system which contain a generator, transformers, circuit breakers, cables, loads, measurement blocks, controlling circuits of relays, relays as differential relays for power transformer with back up of over voltage relay, over current relay for transformer with back up of fuse protection system, and lastly I create a load and its over load protection relays, these all relays are design on basis of digital differential relays.
Keywords: transformer, inrush current, differential relay

I. INTRODUCTION

In the developing world all operations require healthy and reliable supply of electrical energy. Transformers are put to various types of uses. They form an integral part of all electrical and electronic devices we use. Transformer is a very important and costly component of the power systems. The critical motive is the reduction in the time duration and frequency with which the power outages occur. Hence this results in demand of an immaculate and reliable transformer relay system for protection. The demand lay stress on the need for high operating speed which ensures lesser detection and clearing time for faults. No tripping under fault conditions and hence dependability is also a major requirement for the rising demands. Due to all these reasons the job of power transformer protection has become a serious and challenging objective. The protective relaying system include devices that detect the occurrence of a fault, recognize its class type and location at which it is taking place, indicate the inception time of the fault and detect other abnormal faults in the vicinity. Henceforth the relaying system initiates the steps to be taken from opening of circuit breakers to isolation of the faulty element of the electrical power system. Recently microprocessor based relays are used as an alternative to solid state and electromechanical relays due to growth in the field of signal processing and digital electronics. Softwares are used in microprocessor based relay to understand signal characteristics and implement logic. Digital algorithms are used in the microprocessor based relays for successful and efficient transformer protection. In industries transformers are mainly used for metering and security purposes in high voltage circuits. When a lightly loaded or unloaded transformer is connected to the system disruptive transients are likely to occur. Power transformer protection scheme has to deal with energizing situations like magnetizing inrush current. The inrush current can cause faulty operation of the relay as it is nearly 10 times the full load current. The magnitude of inrush current is sometimes comparable to the internal faults and can cause circuit breaker to operate erroneously. These issues do not occur in other equipments of the power system and are limited to transformers. The conventional approach of differential protection which involves current measurement and analysis on both primary and secondary side, hence, is not reliable to function effectively in such cases and will trip falsely in inrush conditions. Largely in all the digital fault detection algorithm combination of differential logic with harmonic restraint logic is used because inrush current contain a considerable amount of second harmonic component.

II. TRANSFORMER

A transformer is a motionless device comprising coils attached through a magnetic medium connecting two ports at different voltage levels (in general) in an electric structure allowing the exchange of electrical energy between the ports in either direction via the magnetic field. The transformer is one of the generally vital component of a variety of electrical circuits ranging from low-power, low-current electronic and control circuits to very high-voltage power systems. Transformers are built in an unforeseen range of sizes from the miniature units used in communication systems to monsters used in high-voltage transmission systems, weighing hundreds of tons. A circuit model and presentation examination of transformers is necessary for thoughtful of many electronic and control systems and round about all power systems. The transformer being an electromagnetic device, its examination significantly aid sin understanding the operation of electromechanical energy conversion devices which also use magnetic field but the interchange of energy is between electrical and mechanical ports. The most important responsibilities performed by transformers are: (i) shifting voltage and current levels in electric power systems, (ii) alike source and load impedances for maximum power shift in electronic and control circuitry, and (iii) electrical isolation (isolating one circuit from an extra or isolating dc though maintaining ac continuity between two circuits). Transformers are used extensively in ac power systems because they make possible power generation at the most desirable and economical level (10–20 kV), power transmission at an economical transmission voltage (as high as 400–1000 kV) and power utilization at most convenient distribution voltages (230/400 V) for industrial, commercial and domestic purposes but in industrial applications voltages may have to be as high as 3.3, 6.6 or 11 kV for large motors.

In communication and electronic systems where frequency ranges from audio to radio and video, transformers are used for a wide variety of purposes. For instance input/output transformers (used to connect the microphone to the first amplifying stage/to connect the last amplifying stage to the loudspeaker) and inter stage transformers are to be found in radio and television circuits. Indeed the transformer is a device which plays an important and essential role in many facets of electrical engineering. The transformer has Np turns of wire on its primary side and Ns turns of wire on its secondary side. 1lle relationship between the voltage Vp(t) applied to the primary side of the transformer and the voltage Vs(t) produced on the secondary side is

$$\frac{Vp(t)}{Vs(t)} = \frac{Np}{Ns} = a \quad (1)$$

where a is defined to be the turns ratio of the transformer:

$$\frac{Np}{Ns} = a \quad (2)$$

The relationship between the current ip(t) flowing into the primary side of the transformer
and the current is(t) flowing out of the secondary side of the transformer is

$$Np * ip(t) = Ns * is(t) \quad (3)$$

$$\frac{ip(t)}{is(t)} = \frac{1}{a} \quad (4)$$

In term of phasor quantities, these equations are

$$\frac{Vp}{Vs} = a \quad (5)$$

$$\frac{Ip}{Is} = \frac{1}{a} \quad (6)$$

Notice that the phase angle of Vp is the same as the angle of Vs and the phase angle of Ip is the same as the phase angle of Is. The turns ratio of the ideal transformer affects the magnitudes of the voltages and currents, but not their angles.

Mathematical Derivation Of Inrush Current

An un-magnetized transformer core is taken into account initially. Keeping the secondary side open, the primary side is supplied with voltage v(t). Equation gives the supply voltage.

$$v(t) = Vm\sin(wt + \theta) \quad (7)$$

The voltage applied depends upon the primary current and core flux.
The following equation gives the applied voltage.

$$V(t) = Ri(t) + \frac{Nd\varphi(t)}{dt} \quad (8)$$

$$v(t) = \frac{Nd\varphi(t)}{dt} \quad (9)$$

$$\varphi(t) = \frac{1}{N}\int_{-t}^{\infty} V(t)dt \quad (10)$$

$$\varphi(t) = \varphi\text{residual} - \emptyset\text{m}[\cos(\omega t + \theta) - \cos\theta]$$
(11)

$$\varphi_m = \frac{V_m}{N_\omega} \quad (12)$$

$$\varphi(t) = -\varphi_m[\cos(\omega t + \theta)] + C$$
(13)

The magnitude of integration constant shown in equation (13) depends on the voltage phase angle during switching instant and remnant flux in the core of the transformer. Flux obtained if switching of transformer takes place at peak voltage value is shown in equation

$$\varphi(t) = -\varphi_m[\cos(\omega t)] \quad (14)$$

Neglecting residual flux, $\varphi_{residual} = 0$

Hence the integration constant C reduces to zero. Variation in flux with respect to time is

$$\varphi(t) = \varphi_m\left[\sin\left(\omega t - \frac{\pi}{2}\right)\right] \quad (15)$$

Flux obtained when transformer energization is at voltage zero,

$$\varphi(t) = -\varphi_m[\cos(\omega t)] + \varphi_m$$
(16)

Here, $C = \varphi_m$

At
$\omega t = \pi$,
the flux has magnitude 2φm this is two times the maximum value of flux when transformer is operating normally.
When switching at zero voltage takes place inrush current of high magnitude is obtained as shown in Fig 1.0

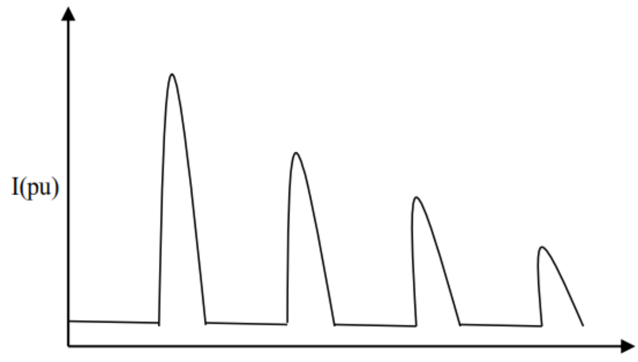

Fig. 1 Inrush Current obtained at 0 degree switching

III. CIRCUIT BREAKER

It is a mechanical switching device capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time, and automatically breaking currents under specified abnormal circuit conditions such as those of short circuit faults. The insulating medium in which circuit interruption is performed is designated by suitable prefix, sulphur hexafluoride (SF6) CB, vacuum CB, etc.

Fault Clearing Time of CB

The fault clearing time is the sum of relaying time and breaker interrupting time. This various components of the fault clearing time of the CB are defined as follows: Relay time = Time from fault inception to the closure of trip circuit of CB Breaker opening time = Time from closure of the trip circuit to the opening of the contacts of the CB Arcing time = Time from opening of the contacts of CB to final arc extinction. Breaker interrupting time = Breaker opening time + Arcing time Fault clearing time = Relaying time + Breaker

interrupting time
The relaying time for electromagnetic relay can vary from about one cycle to five cycles. Static relays are faster than electromagnetic relays. Numerical relays give very fast operation and their relaying time is within one cycle. The contact opening time of the circuit breaker may be between one and three cycles. The arcing time now generally between one and two half cycles, depending upon the instant in the current half cycles at which the contacts part.

IV. DIFFERENTIAL RELAY PROTECTION

Generally Differential protection is provided in the electrical power transformer rated more than 5MVA. The Differential Protection of Transformer has many advantages over other schemes of protection. The faults occur in the transformer inside the insulating oil can be detected by Buchholz relay. But if any fault occurs in the transformer but not in oil then it can't be detected by Buchholz relay. Any flash over at the bushings are not adequately covered by Buchholz relay. Differential relays can detect such type of faults. Moreover Buchholz relay is provided in transformer for detecting any internal fault in the transformer but Differential Protection scheme detects the same in more faster way. The differential relays normally response to those faults which occur inside the differential protection zone of transformer.

SIMULATION
This proposed scheme is related to how transformer is protect from fault condition , so here I am using different types of fault and protection scheme which is related to differential scheme. In this simulation, I am using 38kv generators, transformer with different rating which are as 10 MVA star and star grounded connection have KVA/MVA rating and another 10 MVA delta and star grounded connection have HT/LT rating. Generator1 In this Matlab/Simulation, Generator1 is using in proposed system with 38KV as three phase source for system. Generator1 configuration is star grounded, where phase to phase voltage is 38e3 and X/R ratio is 7.

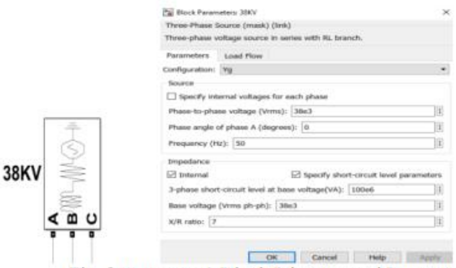

Fig. 2 Generator1 Block Diagram and Parameters

In Generator1 three phase short circuit level at base voltage is 100e6 and base voltage is 38e3. Generator1 is provide supply to transformers KV/MV T141 and HT/LT T11. Generator2 In this Matlab/Simulation, Generator2 is using in proposed system with 38KV1 as three phase source for system.

Generator2
configuration is star grounded, where phase to phase voltage is 38e3 and X/R ratio is 7.

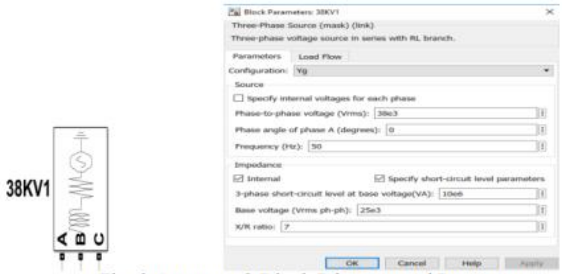

Fig. 3 Generator2 Block Diagram and Parameters

In Generator2 three phase short circuit level at base voltage is 10e6 and base voltage is 25e3. Generator2 is provide supply to transformers KV/MV T142 and ht/LT T12.

Transformers
In this simulation, there are two types of transformers used with different rating and parameters. Firstly KV/MV T141 and HT/LT T11 used for system one where there source is Generator1. Secondly KV/MV T142 and ht/LT T12 used for system one where there source is Generator2. KV/MV connection is StarStar-grounded and HT/LT connection is Delta-Star-Grounded.

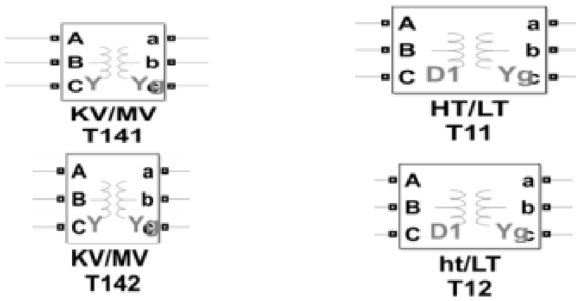

Fig. 3 Block Diagram of Transformer

Short Circuit Current Fault
Short- Circuit Current: The current in electrical circuit where a short circuit occurs. Forthcoming short-circuit current: the shortcircuit current which would arise if the short circuit were replaced by a perfect connection having small impedance without modification of the incoming supply. Symmetrical short-circuit current: root-mean-square value of the symmetrical alternatingcurrent (a.c.) component of a forthcoming short-circuit current, captivating rejection account of the direct-current (d.c.) component. In this simulation, I am generating different types of faults on different points. Which images are given below.

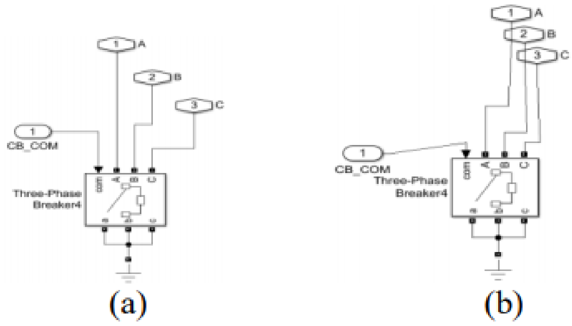

Fig. 4 Block Diagram of Three Phase Fault

In fig.(a), this three phase fault is near to Transformer secondary winding and within the zone of transformer protection by which this is consider as a internal fault of transformer. This fault placed between the point 7 and point 6 where the voltage is V_{abc_7} and V_{abc_6} and the current between these points are I_{abc_7} and I_{abc_6}. In fig.(b), this three phase fault is near to Transformer secondary winding and within the zone of transformer protection by which this is consider as a internal fault of transformer. This fault placed between the point 9 and point 8 where the voltage is V_{abc_9} and V_{abc_8} and the current between these points are I_{abc_9} and I_{abc_8}.

Relays in Simulation

Firstly I am going to introduced my first relay which is a differential relay, In this simulation, I am taking values of V_{abc_7}, V_{abc_6}, I_{abc_7}, I_{abc_6}. Here for differentiation purpose I am using the RMS values of these quantities. For comparison comparator blocks are used, there different types of converter used for converting the values.

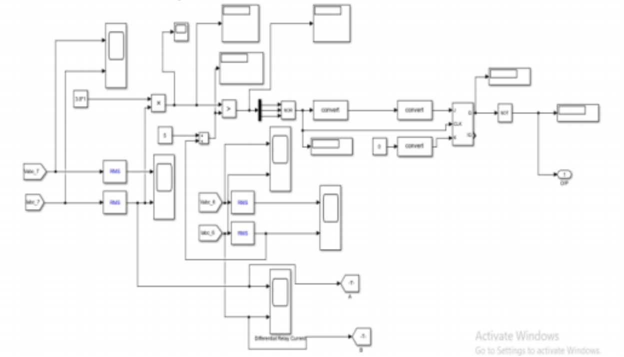

Fig. 5 Block Diagram of Differential Relay1

This differential relay connected with MVCB circuit breaker which is placed near point 6. This relay will operate if any fault accrued at KV/MV transformer.

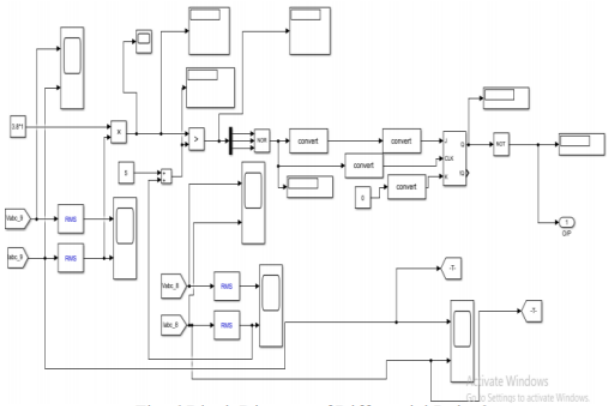

Fig. 6 Block Diagram of Differential Relay2

In this simulation, I am taking values of V_{abc_8}, V_{abc_9}, I_{abc_8}, I_{abc_9}. Here for differentiation purpose I am using the RMS values of these quantities. For comparison comparator blocks are used, there different types of converter used for converting the values. This differential relay connected with MVCB circuit breaker which is placed near point 8. This relay will operate if any fault accrued at KV/MV transformer.

Simulation Result Analysis

In my simulation there I am using two differential relays, their modelling are same but the input values are different.

Differential Relay1 Without Fault

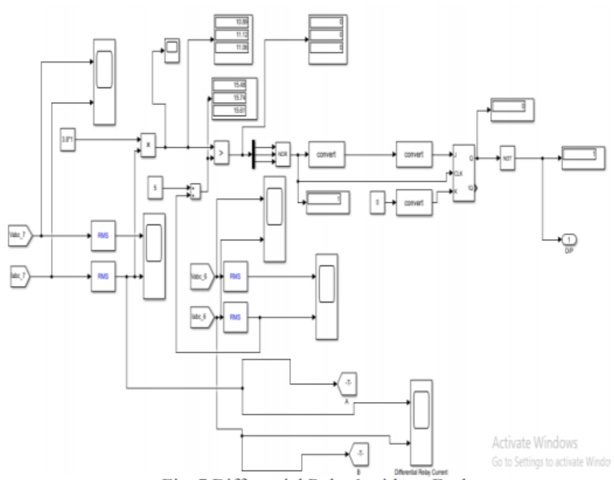

Fig. 7 Differential Relay1 without Fault

In differential relay1 Iabc_7 RMS and Iabc_6 RMS are used for comparison. Constant 3.8*1 value used for Iabc_7 RMS and constant 5 value used for Iabc_6RMS. In this relay V_{rms}= 38e3 Volt. Iabc_7 Rms values are 15.43, 15.87, 15.74 and Iabc_6RMS values are 10.89, 11.12, 11.06.

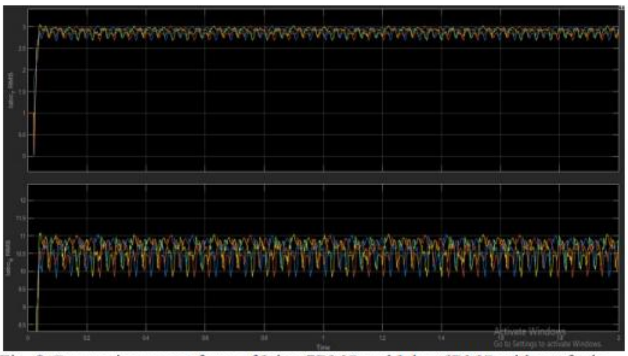

Fig. 8 Comparison waveform of Iabc_7RMS and Iabc_6RMS without fault

Above the comparison waveforms of Iabc_7RMS and Iabc_6RMS without fault, whose values are as Iabc_7RMS= - 0.35689 to 3.42378 and Iabc_6RMS= -1.3365 to 12.45371

Differential Relay 1 With Fault

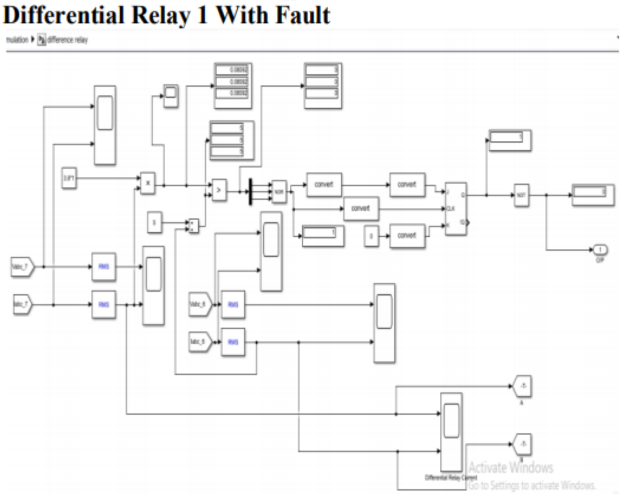

Fig. 9 Differential Relay1 with Fault

In differential relay1 Iabc_7 RMS and Iabc_6 RMS are used for comparison with fault. Constant 3.8*1 value used for Iabc_7 RMS and constant 5 value used for Iabc_6RMS. In this relay V_{rms}= 38e3 Volt. Iabc_7 Rms values are 0.08092, 0.08092, 0.08092 and Iabc_6RMS values are 5, 5, 5.

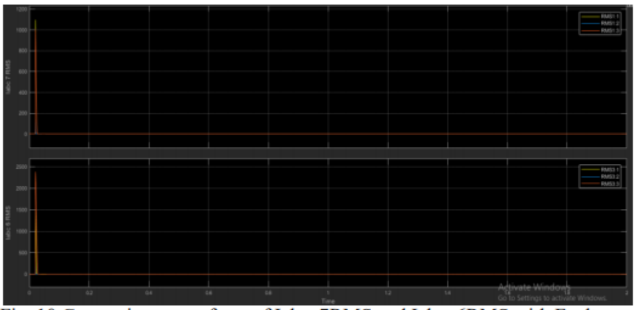

Fig. 10 Comparison waveform of Iabc_7RMS and Iabc_6RMS with Fault

Above the comparison waveforms of Iabc_7RMS and Iabc_6RMS with fault, whose values are as Iabc_7RMS= -137.04814 to 1233.61653 and Iabc_6RMS= -298.50133 to 2686.51193

Differential Relay 2 Without Fault

In differential relay1 Iabc_9 RMS and Iabc_8 RMS are used for comparison. Constant 3.8*1 value used for Iabc_9 RMS and constant 5 value used for Iabc_8RMS. In this relay V_{rms}= 25e3 Volt. Iabc_9 Rms values are 3.502, 5.172, 5.025 and Iabc_8RMS values are 8.671, 10.13, 9.895

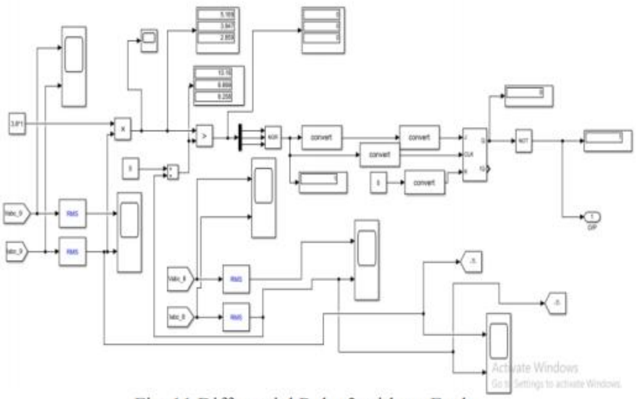

Fig. 11 Differential Relay2 without Fault

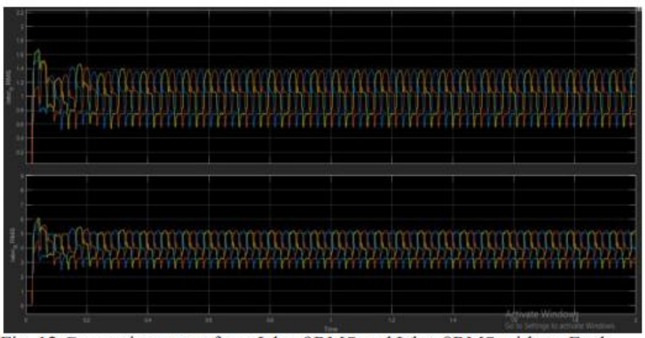

Fig. 12 Comparison waveform Iabc_9RMS and Iabc_8RMS without Fault

Above waveforms are Iabc_9RMS and Iabc_8RMS without fault. Here maximum values of graph are Iabc_9RMS= -0.18623 to 1.87991 and Iabc_8RMS= -0.67136 to 6.82073.

Differential Relays2 With Fault

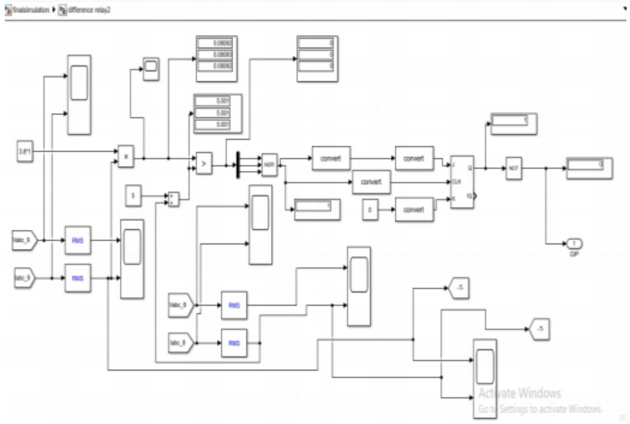

Fig. 13 Differential Relay2 with Fault

In differential relay1 Iabc_9 RMS and Iabc_8 RMS are used for comparison with fault. Constant 3.8*1 value used for Iabc_9 RMS and constant 5 value used for Iabc_8RMS. In this relay V_{rms}= 25e3 Volt. Iabc_9 Rms values are 0.08093, 0.08094, 0.0893 and Iabc_8RMS values are 5.001, 5.001, 5.001.

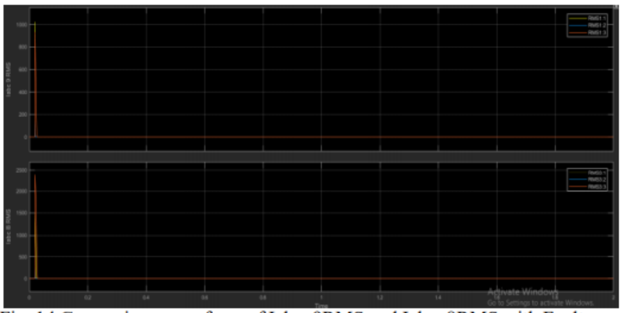

Fig. 14 Comparison waveform of Iabc_9RMS and Iabc_8RMS with Fault

Above waveforms are comparisons between Iabc_9 RMS and Iabc_8 RMS with fault. Here maximum values of graph are Iabc_9 RMS= -127.91616 to 1151.42884 and Iabc_8 RMS = - 298.49959 to 2686.50218

TABLE I
DIFFERENTIAL RELAY1

	WITHOUT FAULT	WITH FAULT
Vrms ph-ph	38e3	38e3
Vabc_7	-89131.33232 to 89447.63042	-135075.50164 to 113498.60407
Vabc_7RMS	-4061.09392 to 36559.84524	-4245.20937 to 38216.88431
Iabc_7	-13.56746 to 12.98019	-3129.18413 to 3508.84278
Iabc_7RMS	-0.35689 to 3.42378	-137.04814 to 1233.61653
Vabc_6	-22833.24363 to 22909.65987	-17691.52712 to 17689.79164
Vabc_6RMS	-1071.1479 to 9650.33106	-1093.16178 to 9848.45605
Iabc_6	-48.55117 to 46.97352	-6084.05524 to 6132.58008
Iabc_6RMS	-1.3365 to 12.45371	-298.50133 to 2686.51193

TABLE II
DIFFERENTIAL RELAY2

	WITHOUT FAULT	WITH FAULT
Vrms ph-ph	25e3	25e3
Vabc_9	-104795.28372 to 99362.15954	-15848.23383 to 145289.5452
Vabc_9RMS	-5105.22275 to 45957.00477	-4774.83875 to 42983.54878
Iabc_9	-9.48589 to 9.48368	-3130.25898 to 3509.70118
Iabc_9RMS	-0.18623 to 1.87991	-127.91616 to 1151.4288
Vabc_8	-27363.10395 to 25739.43456	-18294.74786 to 17787.57825
Vabc_8RMS	-1344.80379 to 12113.23415	-1119.14042 to 10082.26374
Iabc_8	-32.70856 to 33.61024	-6082.94014 to 6132.17617
Iabc_8RMS	-0.67136 to 6.82073	-298.49959 to 2686.50218

In this paper, after modeling of digital differential relay compare its data with fault and without fault condition, and here results show change in current and voltage values during these conditions. Also compare model1 data to model2 data which are successfully done and its shows the sensitivity of relay. Digital differential protection has vast future. Presently digital relays are commonly used in industries, transmission and discom. As I present the modeling of numerical differential relay so in future or further work, In this modeling, apply fuzzy logic based relaying which enhanced fault detection sensitivity.

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