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MODELING AND SIMULATION OF DIFFERENTIAL PROTECTION FOR A 2X15MVA, 33/11KV INJECTION SUBSTATION USING MATCHING CURRENT TRANSFORMER

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ABSTRACT

Although there has been a noticeable decrease in operating and maintenance costs due to the size and capacity increase of power transformer units, there is always a risk of power supply interruption if a transformer breaks down due to an internal fault. Therefore, to protect the transformer against internal faults, differential protection has been put in place, but the differential protection scheme has been facing one or more challenges. In this research work, modelling and simulation of a differential protection scheme for a 2x15MVA injection substation using a Matching Current Transformer (MCT) and the conventional relay was successfully carried out using MATLAB/Simulink software. The methodology adopted was to model and simulate a differential protection scheme with a conventional relay and matching current transformer under the following fault conditions: terminal, short circuit, and inter-turn faults. The results obtained in graphical forms show that the differential protection scheme with the Matching Current Transformer (MCT) effectively isolates the power transformer from all the internal fault conditions and keeps the transformer intact in the system when there is no fault. However, it was noticed from the graph that there was a lag in the response of the protection scheme to the fault. Therefore, a digital relay for the protection scheme will perform better and faster.

Keywords: Substation, Differential Protection, Matching Current Transformer, Conventional Relay, MATLAB/Simulink

1. INTRODUCTION

Due to technological advancements, very large-capacity transformers are now manufactured (Das et al., 2020). Costs associated with operation and maintenance have been significantly reduced thanks to the growing size and capacity of transformer units (Godina et al., 2015). Nonetheless, if a transformer malfunctions, there is always a chance that power supplies will be cut off (Singh et al., 2019). Even with all safety measures followed throughout the design, production, assembly, erection, and installation of a transformer, an appropriate protection strategy must still be in place to avoid a forced outage (Dola & Chowdhury, 2006). The defects a transformer is susceptible to when it is in operation, their causes and the necessary protective plan must be understood. The types of faults that can affect a transformer are faults or external faults and internal faults (Emechebe, 2021). These faults create electro-mechanical and thermal stresses in the windings that could eventually cause the transformer to fail, so they must be cleared on time or after a predetermined time. However, because the transformer could be damaged during a fault, faster and more selective protection was needed for the power system to continue operating continuously. To this end, differential protection was used with matching current transformers to correct current mismatch and compensate for phase shift; by defining its zones using current transformers, the differential relay could provide 100% selectivity, and tripping time could be controlled under one cycle. This was accomplished by comparing the currents entering the transformer (Azizan et al., 2019). Any internal fault will result in a trip by displaying a differential current. In a perfect world, this would be simple to accomplish. Any transformer protection ought to function under both internal and external failures. When there was a specific current difference between the transformer's primary and secondary sides, the differential relay's principal job was to alert the circuit breaker (Azizan et al., 2019). The current output from Current Transformers 1 (CT1) and current transformer 2 (CT2) to the differential relay will be equal under normal operating circumstances. A differential current will be generated if the power system experiences internal problems. When designing a proper protection scheme, the fault must be inside the protective zone (Azizan et al., 2019). After that, the defective zone needs to be isolated from the rest of the power system by taking the appropriate measures.

1.1 Recent Development

The differential protection scheme for the protection of power transformers has faced many challenges in recent years. The challenges include phase shift, unmatched CT features, ratio changes due to tapping, and magnetising inrush current. (Emechebe, 2021) . Researchers have done a lot of work to solve the problem of magnetising inrush current, but little has been done to solve the problem of phase shift and unmatched CT characteristics. (Nassim , et al., 2022) constructed a novel transformer differential protection strategy that considers CCFs and various disturbances based on the self-adaptive biased characteristic curve. First, the superior properties of the measured differential current of the transformer at various levels were extracted using the maximum overlap discrete wavelet transform (MODWT). Next, a new self-adaptive biased characteristic curve was created in various operating situations using MATLAB software to calculate the duty cycle (D) values of energy coefficients retrieved in each periodicity. Ultimately, the percentage differential protection operation was modified using the new adaptive characteristic curve zones as a basis. Using EMTP software, differential current sampling was carried out on a real three-phase transformer under various operating situations. According to the simulation results, the suggested adaptive differential protection strategy can reliably identify various faults and events occurring in the transformer. (Luqman & Mohsin, 2021) employed the Simulink program, whose Simscape module offers all block sets, to verify the most recent differential relay design, which is far more dependable than the conventional one. (Ihedioha, 2016) Provided relay-based differential protection for power transformers. A big power transformer's differential protection relays were examined using the MATLAB / SIMULINK software. The fundamental strategy was to guard against internal failures in the power transformer and stop interruptions caused by external operation conditions. The power transformer relay's trip time was observed to be 0.05 seconds. The outcome shows that the suggested differential relay is a suitable action. The proposed relay could distinguish between inrush, fault, and no-fault situations.

Zitouni (2022) designed a new method that compares the amplitude of the negative sequence currents with a digital discriminator. Turn-to-turn faults were distinguished from others using the internal/external fault classification system. Utilising the negative sequence currents served as the foundation for the suggested process. This novel approach uses an ameliorated circuit to locate minor flaws inside power transformer coils and differentiate inner faults from external faults. This research developed a novel technique that compares the amplitudes of the negative sequence currents and calculates the related phase angle shifts. The MATLAB/Simulink environment has verified the performance of the suggested process. The simulation's outcomes demonstrated the effectiveness of the recommended process.

Therefore, this research project will simulate a differential protection scheme for a 2X15MVA, 33/11KV injection substation utilising MATLAB/SIMULINK. (Ahmed, n.d.) as the simulation program and a matching current transformer to address the issue of mismatched CT characteristics and phase shift.

2. MATERIALS AND METHOD

The proper choice of standard CT values following the calculated current value for the transformer's primary and secondary sides using the power equation is as follows. (Emechebe, 2021)

Primary full load current,

$$I_1 = \frac{S}{\sqrt{3}\times V_1} \tag{1}$$

Where S is the transformer rating in MVA (15MVA)

I_1 is the primary full load current in A

V_1 is the primary full load voltage in V (33KV)

Primary full load current $I_1 = \frac{15x10^6}{\sqrt{3}x33x10^3} = 262.43$A

So, the standard CT for the primary side will be 300/5A

$$\text{Secondary full load current } I_2 = \frac{S}{\sqrt{3}\times V_2} \tag{2}$$

Where S is the transformer rating in MVA (15MVA)

I_2 is the secondary full load current in A V_2 is the secondary full load voltage in V (11KV)

Secondary full load current, $I_2 = \frac{15x10^6}{\sqrt{3}x11x10^3} = 787.3$A

So, the standard CT for the secondary side will be 800/5A

$$\text{Primary full load current in CT secondary} = \frac{I_1}{CTR_1} \tag{3}$$

The primary full load current in CT secondary will be: 262.43x$\frac{5}{300}$ = 4.37A

$$\text{Secondary full load current in CT secondary} = \frac{I_2}{CTR_2} \tag{4}$$

Secondary full load current in CT secondary will be: 787.3x$\frac{5}{800}$ = 4.92A

The secondary transformer winding is in Star, the secondary CT must be connected in Delta, so the CT's secondary line current to the differential relay will be

$$\sqrt{3}\text{x}4.92 = 8.522\text{A} \tag{5}$$

As a result, the primary CT secondary line current of 4.374A and the secondary CT secondary line current of 8.522A must be equal. To accomplish objective one, the matching CT was used. The Differential Protection Scheme using Matching CT to correct for phase shift and current mismatch is depicted in figure: Figure 1 shows the Differential Protection Scheme using Matching CT to correct the current mismatch and compensation for phase shift. The 15MVA three-phase transformer has the 300/5 current transformer (CT) connected to its primary and 800/5 CT connected to its secondary. The output of the primary CT goes to the relay circuit directly. In contrast, the output of the secondary CT goes to the matching current transformer (MCT) to correct the current mismatch so that the current going into the relay circuit from the secondary CT will be equal to the current from the primary CT. This particular current is called the operating current (Iop). When there is no fault in the system, Iop will be zero, so there will be no trip signal to the circuit breaker, and the circuit breaker will remain closed. When a fault occurs, Iop increases in magnitude and causes the operating coil to close the trip circuit contacts, sending a trip signal to the circuit breaker, which opens and isolates the transformer from the fault.

2.1 Circuit diagram of the Differential Protection Scheme

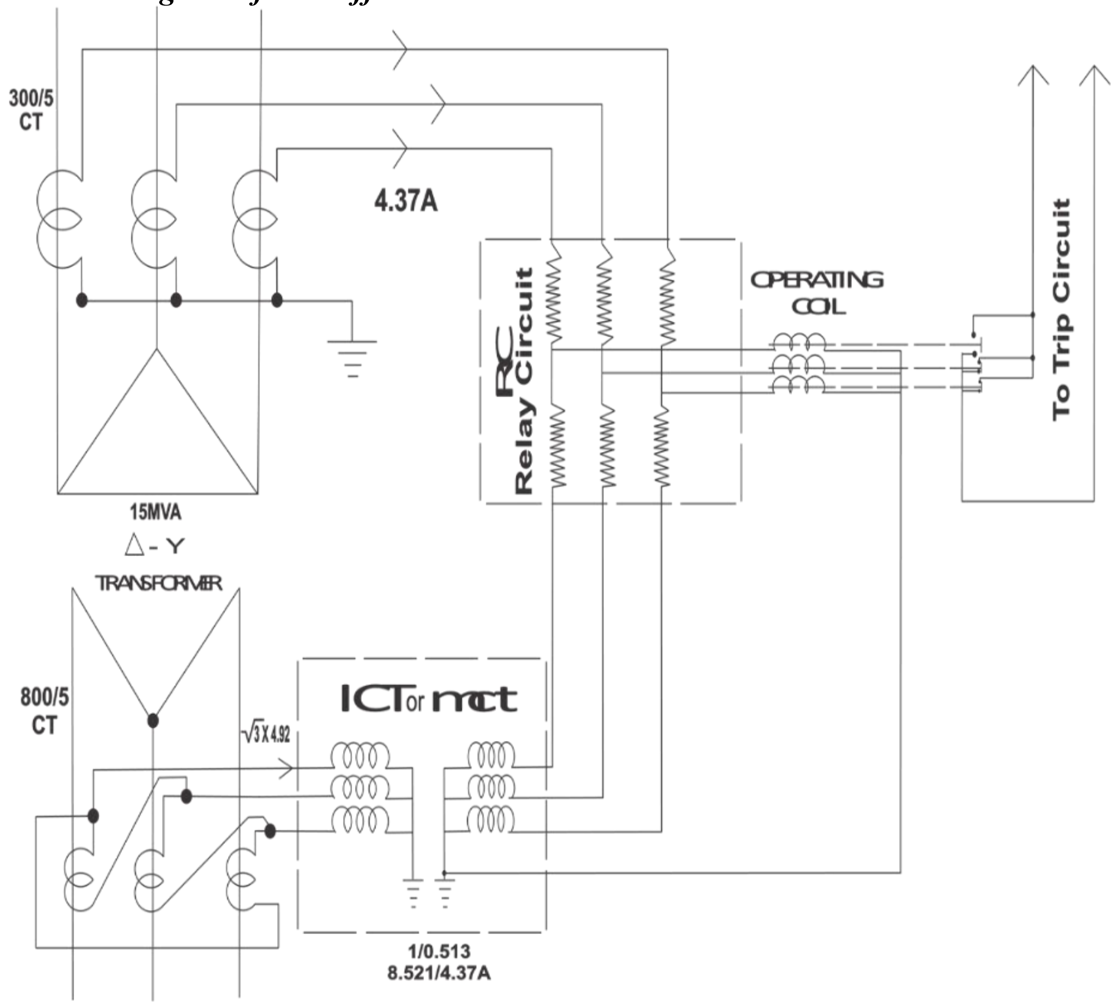

Figure 1: Differential Protection Scheme for a 2X15 MVA Transformer with Matching Current Transformers (MCT) (Emechebe, 2021)

2.2 Modeling of the Differential Protection Scheme

Figure 2 shows a straightforward simulation circuit made with the MATLAB Simulink program. Here, a phase fault is coupled to the distribution line characteristics, three-phase, two-windings transformer, and a phase series RLC load. A three-phase breaker is utilised on each side of the transformer to break the circuit. Three-phase fault blocks are used to create the fault. Three controlled current source blocks, utilised to alter the absolute values extracted from each phase, are utilized with a subsystem block for compensation.

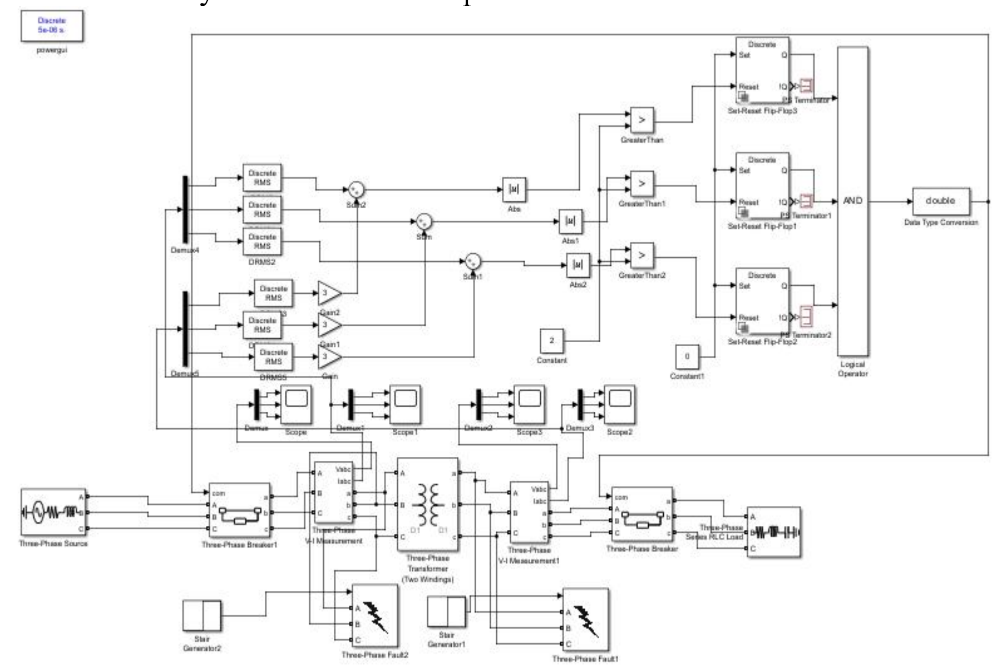

Figure 2: Modeling of Differential Protection for a 2x15MVA, 33/11KV injection substation with Matching Current Transformer (MCT)

Every time a problem arises, the current balance will be zero, relay contacts will close, and a trip signal will be sent to a specific circuit breaker, which will then operate to disconnect the transformer from the fault. The Power Transformer security plan would be designed in a way that prevents and blocks the differential relay from tripping during external faults such as magnetizing inrush and overexcitation, and it should quickly operate the relay tripping during internal faults. As a result, an appropriate distinguishing proof plan has been implemented that is capable of differentiating between the magnetizing inrush, overexcitation, and internal and exterior fault current. The whole differential protection system, including the corresponding current transformer and traditional differential relay, is modeled in Figure 2.

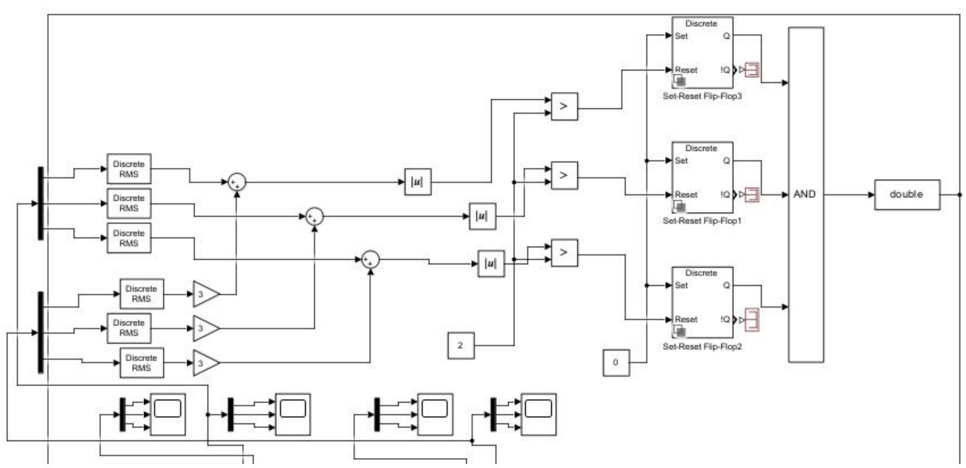

Figure 3: Matching Current Transformer (MCT) Block in the modelling

Figure 3 depicts the subsystem block's contents and the MCT configuration in the modelling (the subsystem block). The subsystem was receiving two inputs: primary and secondary current. Gain blocks, discrete RMS blocks, and sum blocks were used to balance the current flowing through the primary and secondary of the CTs. The digital operating system is the foundation of the relay's control system. A relational operator is employed to compare the required input current and pickup current. The trip signal was generated by the logic operator (AND) and the SR flip-flop, which were coupled to the relational operator's output.

3. RESULTS AND DISCUSSION

This Modelling was done with a conventional differential relay and matching current transformer to correct the current mismatch and phase shift. Then the simulation was done with the following fault conditions: no fault, terminal fault, short circuit fault, and inter-turn fault.

2.1 No-Fault Condition

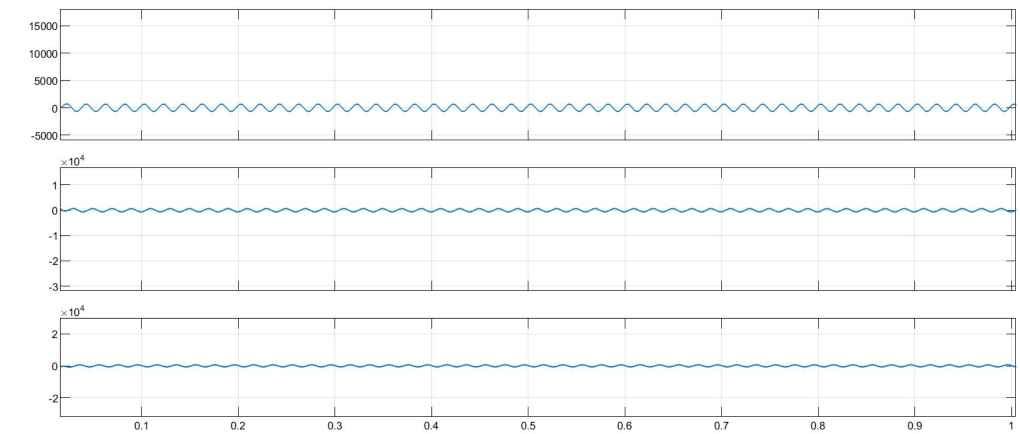

Figure 4: Simulation result when there is no fault and time is set at 0, 0.2, 0.4, 0.6, and amplitude at zero (0). There is no Tripping, and the circuit breaker remains closed.

Figure 4 shows the simulation result when there is no fault, the relay sends no trip signal to the circuit breaker; therefore, the circuit breaker remains closed, and the transformer remains intact in the system. The graph's continuous nature represents the transformer's normal operation under no-fault conditions.

2.2 Terminal Fault Condition

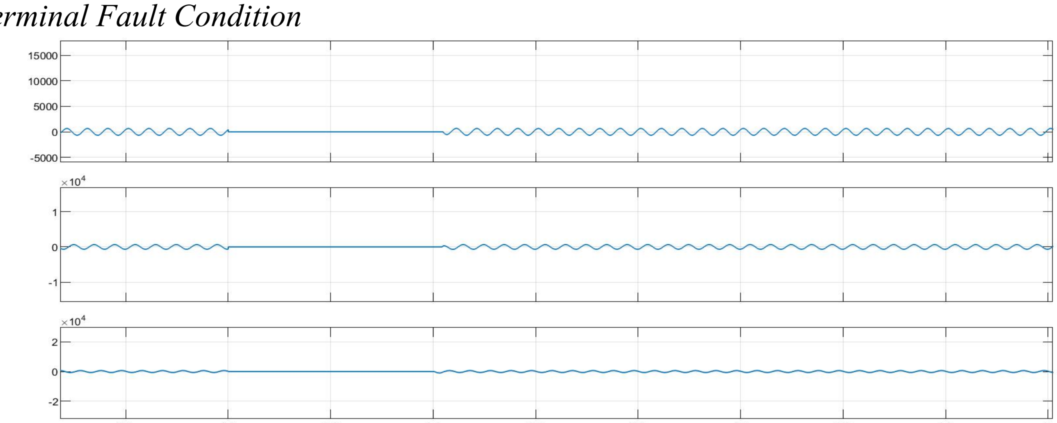

Figure 5: Simulation result when Terminal fault is applied at 0,1,0,0 amplitude and time is 0, 0.2, 0.4, 0.6. Tripping occurs, and the breaker opens at t = 0.2

Figure 5 shows the simulation result when the terminal fault was applied to the system at t=0.2. When the fault was introduced, the relay immediately sent a trip signal to the circuit breaker to indicate an internal fault in the system. This caused the circuit breaker to trip and disconnect the transformer from the power system at t=0.2. The break in the graph at t=0.2 represents the trip and isolation of the transformer from the power system when the terminal fault occurs.

2.3 Short Circuit Fault Condition

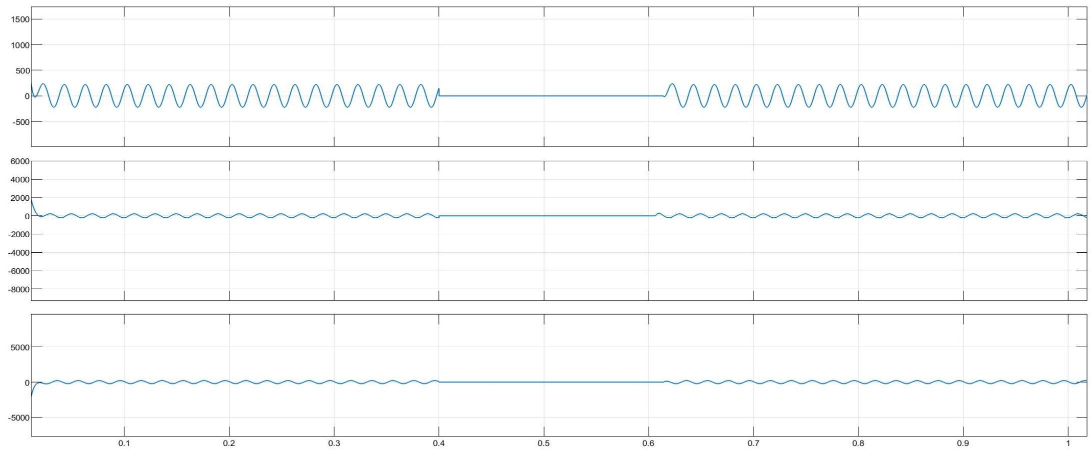

Figure 6: Simulation result when short circuit fault is applied at 0,0,1,0 amplitude and time is 0, 0.2, 0.4, 0.6. Tripping occurs, and the breaker opens at t = 0.4

Figure 6 shows the simulation result when a short circuit fault was applied to the system at t=0.4. When the fault was introduced, the relay sent a trip signal to the circuit breaker to indicate an internal fault in the system, which caused the circuit breaker to trip and isolate the transformer from the power system at t=0.4. The break in the graph at t=0.4 represents the trip and isolation of the transformer from power system when the short circuit fault occurs.

2.4 Interturn Fault Condition

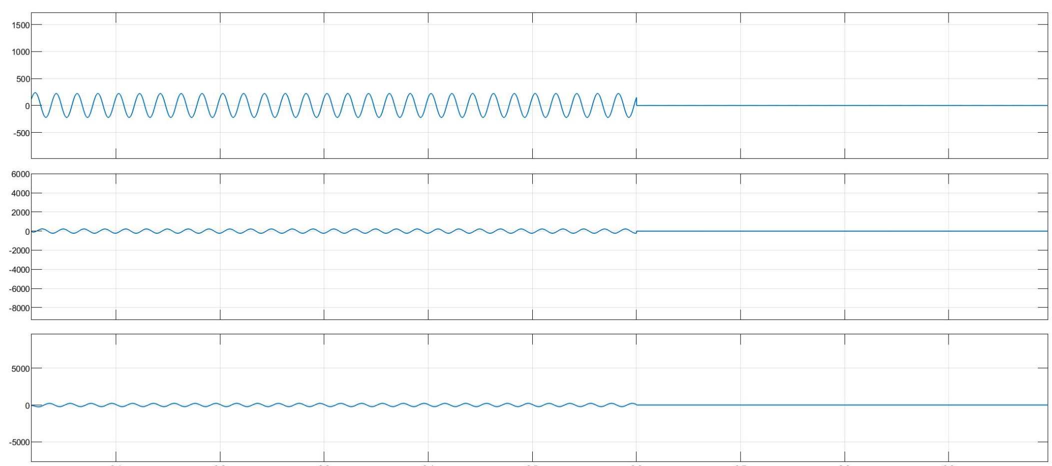

Figure 7: Simulation result when Inter-turn fault is applied at 0,0,0,1 amplitude and time is 0, 0.2, 0.4, 0.6. Tripping occurs, and the breaker opens at t = 0.6

Figure 7 shows the simulation result when an inter-turn fault was applied to the system at t=0.6. When the fault was introduced, the relay sent a trip signal to the circuit breaker to indicate that there was an internal fault in the system, which caused the circuit breaker to trip and the transformer to be isolated from the power system at t=0.6 The break in the graph at t=0.6 represents the trip and isolation of the transformer from power system when the inter-turn fault occurs.

Table 1. Type of fault and the Tripping action of the protection Schemes

S/N	TYPE OF FAULT	PROTECTION SCHEME ACTION
1	No-fault condition	No tripping
2	Terminal fault	Tripping occurs
3	Short circuit fault	Tripping occurs
4	Inter-turn fault	Tripping occurs

Although the protection scheme responds to the fault current, there is a little delay (lag) in its response to the fault current, as observed from the graphs, because the matching current transformer has to do the phase shift and unmatched CT characteristics corrections electromechanically which causes the lag in its response to a fault. Also, the wiring and settings of the MCTs are very cumbersome.

4. CONCLUSION

This Research aimed to model and simulate differential protection for power transformers using Matching Current Transformer (MCT) and conventional differential relay. The modelling and Simulation using the following fault conditions, terminal fault, short circuit fault, and inter-turn fault, were done successfully. When no fault was applied, no tripping took place and the breaker remained intact, when the terminal fault was applied at t=0.2, tripping occurred and breaker trips at t=0.2, when short circuit fault was applied at t=0.4, tripping occurred and breaker trips at t=0.4, when the inter-turn fault was applied at t=0.6, tripping occurred and breaker trips at t=0.6, from the result obtained it can be concluded that the protection scheme can isolate the power transformers from all internal faults in injection substations

5. RECOMMENDATION

The use of a digital relay (Numerical Differential Relay) in place of the matching current transformer and conventional relay will solve the problem of the lag experienced with this particular method better and faster and also, the wiring and setting will be easier.

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