Simulation of differential relay for transformer protection

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Abstract. In electric power system, transformers are an important element and their protection are critical. As the transformer might be damaged during a fault, faster and more selective protection was required. For this purpose, the design of differential protection was utilized. In this study, the differential relay simulation has been successfully done using MATLAB/Simulink. The essential approach is to protect the power transformer against internal faults and avoid interference in the power system. The evaluation has been accomplished at different fault conditions. Several types of faults including double line-to-ground, single line-to-ground and line-to-line faults are studied. Simulation studies were performed and the relays performance with different system parameters and conditions were investigated. The obtained results illustrated for the differential relay represents an appropriate action.

1. Introduction
The appearance of protective relays in a power system is to detect system anomaly and to assassinate proper ways to isolate swiftly only the faulty element from the healthy system. The flashover of lightning and other faults in the transmission line leads to shortage of electricity [1]. The possibility of fault occurrence on the overhead lines is much more due to their greater lengths and liability to atmospheric conditions [2]. There are several methods for the protection of transmission and distribution lines [3-7]. Transmission and distribution networks have moved from being a local entity to becoming a continent spanning machine, which consisted of power plants, wind turbine farms, country spanning transmission
line and etc. The joints connecting all these elements were the transformers. The transformers scale the voltages to connect the lower level distribution networks to the highway of electricity: the transmission network [8].

However, the transformer might be damaged during a fault. Therefore, a faster and more selective protection was required for the continuity operation of the power system. For this purpose, differential protection was utilized. By defining its zones using current transformers, differential relay could provide 100% selectivity, and tripping time could be controlled under one cycle. This was done by comparing the currents flowing into the transformer [9]. Any internal error will show up as a differential current and caused a trip. In the ideal system, this could be done easily. Under the internal and external faults, any transformer protection should be able to operate. The main function of differential relay was to send trip signal to circuit breaker when there is a certain difference current value between primary side and secondary side of the transformer [1]. Current Transformers (CTs) were used to convert the primary current to secondary current and the differential relay can be used to check if there is any differential current.

Under the normal operating condition, the power output to the transformer should be equal to the power input to the transformer. If internal faults happened in the power system, there will be a differential current generated. In order to design a proper protection, the faults need to be located within the protection zone [10]. Then, proper action should be done to isolate the faulty zone from the rest of the power system. Current differential relays were one of the protection devices used to protect the electrical equipment against the internal faults. This is due to the reason that current differential relays have high sensitivity and simplicity. This paper aimed to study the modelling and simulation of differential relay for transformer protection operation using MATLAB/Simulink.

2. Methodology
The power system model was simulated and performed using Simulink/MATLAB. In this model, there are 11/33 kV power system with current relay protection scheme between the transmission line and transformer. Figure 1 showed that the power transformer was connected to a power system consisting of a three-phase power generator. In order to check the switching effect, it feeds the load over this transformer between two circuit breakers, CB1 and CB2.

The differential relay was used to detect the internal fault and generated a trip signal to the associated circuit breakers to segregate the faulted section from the rest of the power system [10]. This protection minimized the harm to transformer and power system. Equation 1 explained the operation of differential relay where the differential relay will operate once the differential current measured from CT1 and CT2 exceed certain value. The differential current that exceed certain value was called the pickup current. In order to make system protected, the breaker will not send a tripping signal if the measured differential current does not exceed the relay’s pickup current. The relay will send a tripping signal if there were internal faults, the differential current formed in relay was higher than the pickup current. After the tripping signal received, the breaker will disconnect and isolate the fault from power system.
Figure 1. Basic configuration of differential relay.

\[ \Delta I = |I_1 - I_2| \]  \hspace{1cm} (1)

where
\[ \Delta I = \text{The differential current} \]
\[ I_1 = \text{The secondary current measured by CT1} \]
\[ I_2 = \text{The secondary current measured by CT2} \]

Figure 2 showed in detail on how the simulation of differential relay has been carried out. Basically, when there was no power loss in ideal transformer, there was no operating current. But in practical, there was an eddy current loss and core loss in transformer. There was also imbalance in phase shifting, tap-changing, CTs ratio and transformer ratio because of the operated current will not be zero. This differential relay was designed to respond to the circuit breaker when there is difference in current from both CTs of transformer in the term of its inconsequential relation to the current flowing from the protecting zone as shown in figure 1.

First, it read the current in transformer of primary and secondary then it will identify the differences between the current measured from the primary side and secondary side of transformers. Then, the fault was created to test the system. The relay will sense any changes in current flow through the transformer. Finally, the information is collected from the results of tripping in the system.
2.1. Circuit Operation
A power system model has been developed using MATLAB/Simulink software. Figure 3 showed the differential relay in power system model. The general overview of the power distribution system consisted of three-phase source connected with three-phase breaker. Then, transmission line was connected to the breaker. In between them, there were three-phase V-I measurement which is used to measure the value of load current. Lastly, a three-phase series RLC load was connected at the end of transmission line which resembled the load for the system.
Figure 4 showed the design of differential relay in Simulink which consisted of two input portals In1 and In2. The In1 and In2 represented the output currents of the CT1 and CT2 respectively. In order to analyse the system, these two input signals would be divided into three parallel paths. All the signals entered a block named amplitude comparator. The first signals entered a block named amplitude comparator. The second signals made the signals to be impressed in the harmonic test and send the result to a block named harmonic comparator.

The amplitudes of both input current In1 and In2 will be compared by amplitude comparator. Then, the amplitude comparator sent an indicating signal to the comparator block and showed the difference between the two signals. At the same time, the harmonic comparator block will receive two signals from two blocks named subsystem. Then, it will send the result to the comparator. The subsystem block will evaluate the input signal to investigate if harmonics exist in this signal.

Figure 4 also illustrated the contents of the subsystem block. There were two input entering the subsystem. There were gain three at input two as the secondary winding of transformer is 33kV, in order to balance the current on the first input of 11kV. The purpose of gain three is to increase the secondary voltage side to become less in transformer.

The control system of relay is based on the digital operating system. The relational operator is used to compare the input current with the pickup current as desired. The output of the relational operator was connected to the SR flip flop.
The basics of SR flip flop was shown in Table 1. Based on the truth table, to make the circuit breaker tripped, all the input “R” of the flip-flop should be connected to ‘0’. All the ‘S’ inputs should be connected to the output of relational operators. When a fault happened, the relational operator will become 1 and with input ‘R’ equal to 0, the flip-flop output (Q) will become 1 (SET). Then, trip signal will be sent.

3. Results and Discussions
The normal conventional relay was simulated in MATLAB using the Simpower system of SIMULINK. The external and internal fault cases were simulated. When external fault appeared and the circuit breakers were closed to connect the transformer, the currents were generated. In designing the differential relay, there must be a relay before circuit breaker that assigns the tripping signal to it after correlate input signals. The currents were measured by current transformers and then introduced to the
relay. The faults were created at three different conditions; at three phase fault 1, three phase fault 2 and three phase fault 3.

![Figure 5](image)

**Figure 5.** Simulation result when no fault occurs in the system.

Figure 5 showed the result for no fault condition in the system. Under this condition, relay did not assign any tripping signal to the breaker hence the signal was in normal condition. Figures 6 and 7 showed the results for three-phase fault created at t=0.1s when fault occurred at location 1 which relay sent a signal to the circuit breaker. Faults were created when three-phase faults at location load 2 trip the circuit breaker at t=0.1s which showed that there were internal faults. Consequently, the transformer was isolated from the grid. Figure 8 showed that there were no fault and no circuit breaker functioned for three-phase I(A) fault at location 3 as it is located as an external three-phase faults.

![Figure 6](image)

**Figure 6.** Simulation result when three-phase fault is occurred at location 1 (L-L-L).
Figures 9 and 10 showed the results for LLG fault created at t=0.1 s in the system where the relay sent signals to the circuit breaker. Faults were created at location 1 and 2, trip the circuit breaker at t=0.1 s shows it was an internal LLG fault. Figures 10 and 11 showed the results for the internal fault LLG. The internal fault LLG was located inside the protected zone and therefore the corresponding relay sent a tripping signal to the circuit breaker.

It was observed that in case of L-L-G fault, only the faulty phase was disconnected by the circuit breaker. Thus, transformer was segregated from the grid. Double line to ground included 15% of power system faults. Figure 11 showed that there were no fault and no circuit breaker function at three phase fault 3 because it was located as outside protection zone and it was an external L-L-G faults.
Referring to Figures 12 and 13, there were small phase difference between the two currents which caused by different source angles at t = 0.1 s. For an internal fault, with the polarity of the current transformers, the current flow into the protected zone from both line terminals. For L-L at phase A and phase B, the relay responses the fault and selectivity open one of the faulted phases so that other phases able to supply power. Line to line included 15 % of power system faults.
For an external fault, the current flow into the line and out of the other. Figure 14 showed the result for external L-L fault on system hence no tripping signal from the differential relay to the circuit breaker. If the fault occurs outside the bounded area, it is not desirable to disconnect the transformer.

**Figure 12.** Simulation result when fault is occurred on phase A and B at three phase fault 1 (L-L).

**Figure 13.** Simulation result when fault is occurred on phase A and B at three phase fault 2 (L-L).

**Figure 14.** Simulation result when fault is occurred on phase A and B at three phase fault 3 (L-L).

Figures 15 and 16 showed the results for internal L-G fault, phase A to ground, at three phase fault 1 and 2. There was an internal fault inside the protected zone relay. The relay sent a tripping signal to
the circuit breaker at created fault $t= 0.1s$ as there are differences between the currents. Simulation result for L-G was shown in Figures 16 and 17. The proposed relay allowed a trip signal to the circuit breaker as fault happen. It was noticed that in case of L-G fault, only the faulty phase was detached by the circuit breaker over relay. The transformer was disconnected from grid as it opened all ungrounded conductors of the faulted circuit.

Figure 17 showed the result for external L-G fault, phase A to ground, at three phase fault 3. On the system, there are no tripping signal from the differential relay to the circuit breaker. The external faults showed that the fault outside the protection zones of the differential relay. In external fault condition, the current over transformer was changed but a decisive differential relay must not give a tripping signal to the circuit breaker. The summary of fault and relay tripped is simulated as stated in Table 2.

**Figure 15.** Simulation result when fault is occurred on phase A and ground at three phase fault 1 (L-G).

**Figure 16.** Simulation result when fault is occurred on phase A and ground at three phase fault 2 (L-G).
Circuit breaker worn for the protection purpose in power system cannot work by its own determination. The circuit breaker sends the tripping signal after correlate input signal with the logic. The result is compared as in Table 2. The tests are conducted in two situations, external faults and internal faults by phases. For faults inside the protection zone, the relay has reacted accurately, at the presences of the located fault. In addition, for external fault in different conditions normally the relay has not operated when fault located at three phase fault 3.

### 4. Conclusions
As conclusion, the differential relay simulation had been successfully done and the results were amazing as all the types of fault tested, triggered the tripping system. The basic approach is to assure the power

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**Figure 17.** Simulation result when fault is occurred on phase A and ground at three phase fault 3 (L-G).

**Table 2.** Type of fault and clearing scheme.

| Type of Fault            | Fault Location | Relay Tripped |
|--------------------------|----------------|---------------|
| Three Phase              | 1              | Tripped       |
|                          | 2              | Tripped       |
|                          | 3              | Not Tripped   |
| Double Line to Ground    | 1              | Tripped       |
|                          | 2              | Tripped       |
|                          | 3              | Not Tripped   |
| Line to Line             | 1              | Not In Phase  |
|                          | 2              | Not In Phase  |
|                          | 3              | Not Tripped   |
| Single Line to Ground    | 1              | Tripped       |
|                          | 2              | Tripped       |
|                          | 3              | Not Tripped   |
transformer across internal faults at created fault $t=0.1s$ and prevent interruption due to other operating conditions. In three phase faults, as fault happen, the transformer is consequently isolated from the grid. In double line to ground and single line to ground, it is observed that only the faulty phase is detached by the circuit breaker over the relay. In line to line fault, there are small differences between two current which caused by different sources angle. The evaluation has been accomplished at different fault conditions. Simulation studies are performed and the relay performance with different system parameters and conditions is investigated. The obtained result illustrate that the proposed differential relay represents an appropriate action.

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