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# IMPROVEMENT OF DIGITAL DIFFERENTIAL RELAY SENSITIVITY FOR INTERNAL GROUND FAULTS IN POWER TRANSFORMERS

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**Abstract**- Digital differential protection is a developed idea of the old system of conventional differential protection, which had made perfect solution to the problems that the old systems suffer. This paper simulates small power system with a differential relay connected to protect the power transformer in this system. The test points are selected to simulate different cases of operation and faults. The first case is for power transformer energization by closing the Circuit Breaker (CB) existing in the primary side of power transformer and analyzing the behaviour of the whole system during energization. In this situation, it was noted that the behaviour of the digital relay did not release a trip signal due to inrush current. The second case is for closing the CB exists in the secondary side of the power transformer. In this case the load starting current will flow and the inrush current component disappeared. Also the digital relay did not release a trip signal. The third case is for creation of an internal fault inside the protected zone. In this case the system was disturbed and the digital relay released a trip signal towards certain CBs in order to isolate the power transformer from the system. The relay responds to the fault after 10.7 msec. The forth case is for creation of an external fault outside the protected zone. In this case, no trip signal was released from the relay.

**Keywords:** Power Transformers, Digital Protection, Faults in Power System, Matlab Simulation.

## I. INTRODUCTION

Transformers are essential and important elements of electric power systems and their protection are critical. Traditionally, transformer protection methods that use its terminal behaviors are based on differential protection and the studies for improvement of transformer protection have focused on discrimination between internal short circuit faults and inrush currents in transformers [1, 2, 11]. If a power transformer experiences a fault, it is necessary to take the transformer out of service as soon as possible so that the damage is minimized. The costs associated with repairing a damaged transformer may be very high. The unplanned outage of a power transformer can also cost electric utilities millions of dollars. Accordingly, high demands are imposed on power transformer protective relays. The requirements include dependability (no missing operations), security (no false tripping), and speed of operation (short fault clearing time) [3].

Over the years, various incipient fault detection techniques, such as dissolved gas analysis [4, 12] and partial discharge analysis [5] have been successfully applied to large power transformer fault diagnosis. Since these techniques have high-cost and some are offline, a low-cost, online incipient fault detection technique for transformers using terminal measurements would be very useful. Online condition monitoring of transformers can give early warning of electrical failure and could prevent catastrophic losses. Hence a powerful method based on signal analysis should be used in monitoring. The method should discriminate between normal and abnormal operating cases that occur in distribution systems related to transformers such as external faults, internal faults, magnetizing inrush, load changes, arcing, etc. One of the most effective methods of protection to protect Power transformers is the *Differential protection* method by using differential relay circuits. This scheme is based on the principle of that the power input to the transformer under normal conditions is equal to the power out. By proper connection of the secondaries of current transformers (CT), under normal conditions, no current will flow into the relay coil. Whenever a fault occurs the current balance will no longer exist and relay contacts will close and release a trip signal to cause a certain Circuit Breakers (CB) to operate in order to disconnect the faulty equipment.

Digital differential protection is a developed idea of the old system of conventional differential protection which had made quite satisfactory solutions to the above mentioned problems. The advances of the art of relays and protection schemes have involved many disturbing compromises. Some of the previous studies will now be presented in order to be familiarized by what the recent researcher have done [6]. Hayward [7] presented in his paper a new type relay using the principle of harmonic restraint, which is able to distinguish between the internal fault and the magnetizing-inrush by their difference in waveform. But also this method is characterized by complicated circuits and consists of mechanical parts. Sachdev, Sidhu and Wood [8] presented a new digital algorithm to detect winding faults in single-phase and three-phase transformers. The proposed algorithm is suitable whether or not it is possible to measure winding currents. A variety of operating conditions simulated on a computer were used to test the algorithm.

Yabe [9] described a new method to discriminate internal fault from inrush current by the sum of active power flowing into transformers from each terminal. To avoid the needless trip by magnetizing inrush current, the second harmonic component is commonly used for blocking differential relay in power transformers. Kasztenny and Kulidjian [3] presented a new inrush restraint algorithm for the protection of power transformers. The algorithm is an extension of the traditional second harmonic restraint. Instead of measuring the ratio between the magnitudes of the second harmonic and the fundamental frequency component, the algorithm considers a ratio between the phasors of the second and the fundamental frequency components of the differential current signal. Guzman, Altuve and Tziouvaras [10] described an approach for transformer differential protection that ensures security for external faults, inrush, and over-excitation conditions and provides dependability for internal faults. This approach combines harmonic restraint and blocking methods with a wave shape recognition technique.

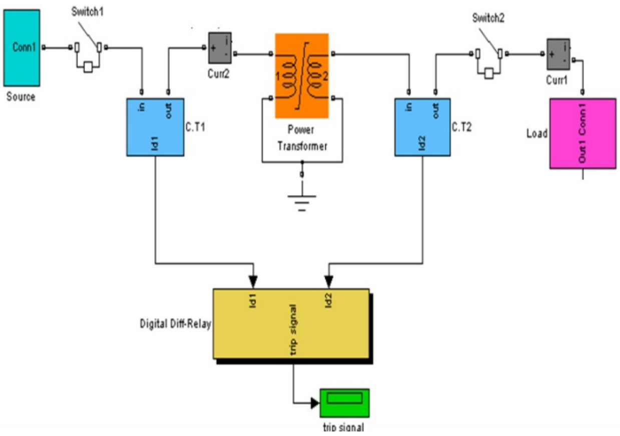


Figure 1. The complete circuit of a small-simulated power system

The objective of this paper is to design new software to simulate an improvement approach of digital differential relay operation. This software will improve and enhance the sensitivity of operation of the digital differential relays that protects power transformers by the discrimination between inrush current and fault current without blocking the relay during the energization of power transformers, as well as avoiding tripping during the operation of tap changer.

## II. DIGITAL SOLUTIONS OF PERCENTAGE DIFFERENTIAL PROTECTION PROBLEMS

This section of the paper consists of simulation of a complete small power system. The digital differential relay is designed using a simulation technique in Matlab Simulink environment. Figure 1 illustrates the single line diagram of the model power system. The ratings of the power transformer used in this system are 400 MVA, 50 Hz, 400/220 kV. Also other transformers with different ratings are tested in this system too but only one of them is selected to illustrate the results obtained. The digital differential relay designed here is implemented to protect the power transformer against internal faults and prevent interruption due to inrush current. Figure 2 illustrates the components of the designed digital differential relay, which consists of two input portals $I_{d1}$ and $I_{d2}$, where, $I_{d1}$ and $I_{d2}$ are the output currents of the $CT_1$ and $CT_2$ respectively. These two input signals would be divided into two parallel paths in order to be analyzed. The first one will lead the signal to enter a block named (*Amplitude comparator*). The second one will make the signal to be impressed in the harmonic test and send the result to a block named (*Harmonic comparator*).

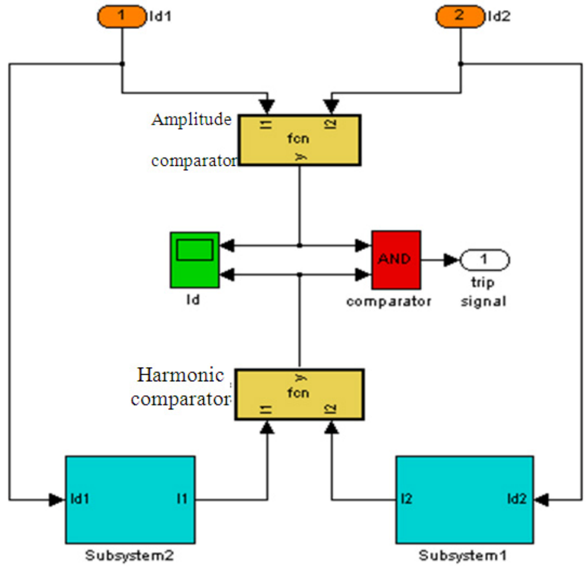


Figure 2. Contents of the designed digital differential relay

Amplitude comparator block will compare the amplitudes of both input current $I_{d1}$ and $I_{d2}$. Then it will send an indicating signal to the comparator block showing the difference between the two signals. Harmonic comparator block will receive two signals from two blocks named (*subsystem*) and send the result to the comparator also as mentioned above. The subsystem block will analyze the input signal to investigate the harmonics exist in this signal.

Figure 3 illustrates the contents of the subsystem block. In this block the signal will be analyzed to determine the percentage value of the second harmonic with respect to the fundamental frequency. This process will be carried out in the harmonic analyzer block, which will compare the two signals coming from the two Fourier Transform blocks (FT) and (FT1). The harmonic analyzer block will make a percentage ratio comparison of the second harmonic with the fundamental. The decision of the harmonic comparator is designed to be taken only at the instant of transients. If the value of the second harmonic at the instant of transient is between 0.3 and 0.7 of the fundamental, then the signal is an inrush current, otherwise it is an internal fault. This harmonic analyzer will send this result to the Harmonic comparator which in turn will receive another signal from the second port and then will send a final report about the harmonics to the final comparator.

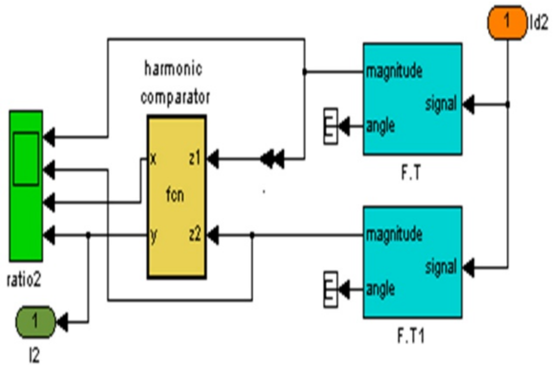


Figure 3. Contents of the subsystem block in the designed digital differential relay

Finally, the final comparator will give the final decision whether there is an internal fault in the protected zone to release a trip signal in order to disconnect the protected element from the system, or that the situation is a magnetizing inrush current or an external fault to restrain the relay, in this case no trip signals will be released.

Figure 4 represents the contents of the CT used in this study. This circuit is designed in this research because in Matlab Simulink there is no CTs can serve this application. This CT as well as the digital relay designed in this research may be considered as new toolboxes to be added to the Matlab library. The transformer used here is a normal saturated transformer of 150 VA, which will work together with the peripherals components connected to it to supply current to the digital differential relay according to the value of the current supplied by the source via power transformer to the load.

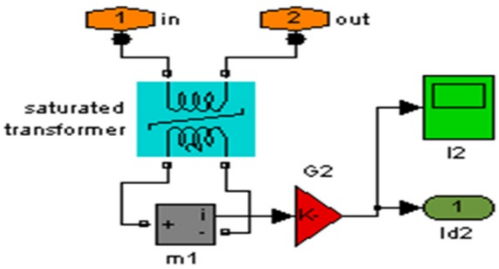


Figure 4. Contents of the CT block in the designed power system

## III. RESULTS AND DISCUSSIONS

The results will be given for four cases of energization and faults, which are:

- Case 1: closing of the CB at the primary side of the power transformer,
- Case 2: closing of the CB at the secondary side of the power transformer,
- Case 3: creation of an internal fault inside the protected zone,
- Case 4: creation of an external fault outside the protected zone.

In each case, the influence of the transient period will be studied to illustrate the results of the four cases.

### A. Case 1: Closing the CB of Primary Side of Power Transformer

In this section of simulation, when the CB at the left side, labeled by Switch 1 in Figure 1, is closed at 0.1 sec just inrush current, as shown in Figure 5, is passing throw the primary circuit of the power transformer and no current will pass to the secondary circuit.

Figure 6 illustrates the ratio of the 2nd harmonic to the fundamental, where the maximum value of the ratio did not exceed 0.5, which is still in the mentioned range of 0.3 and 0.7 of the fundamental. In this case no trip signal is released.

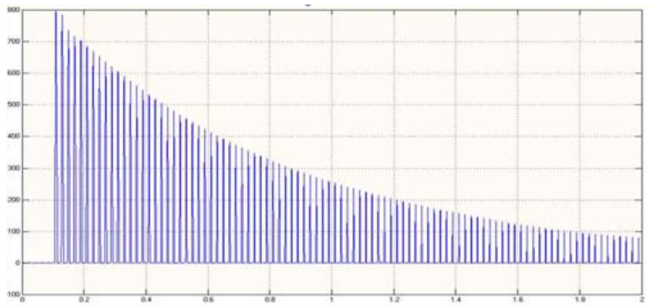

Figure 5. Inrush current wave form resulted from the simulation of the Case 1

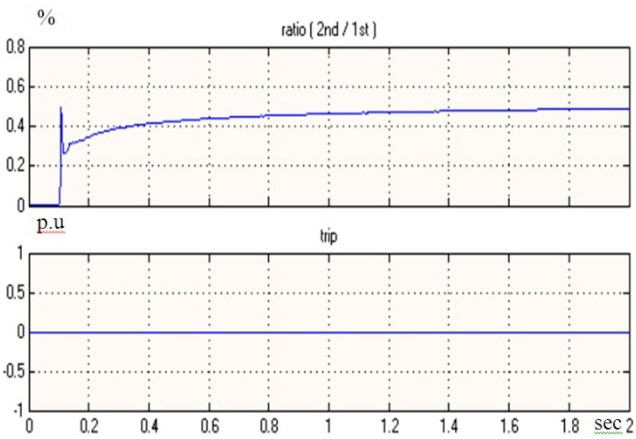


Figure 6. The ratio of the 2nd harmonic to the fundamental and the trip signal of the Case 1

### B. Case 2: Closing the CB of Secondary Side of Power Transformer

After switching of CB1 at 0.1 sec, the CB2 at the right hand side, labeled by Switch 2 in Figure 1 is closed at 0.4 sec. In this case inrush current is disappeared and load current started to flow in the primary and secondary circuits of the transformer as shown in Figure 7.

Figure 8 illustrates the ratio of the second harmonic to the fundamental frequency which is going to zero after 0.4 sec because the current is taking the sinusoidal waveform, which is almost free of harmonics. In this case no trip signal is released.

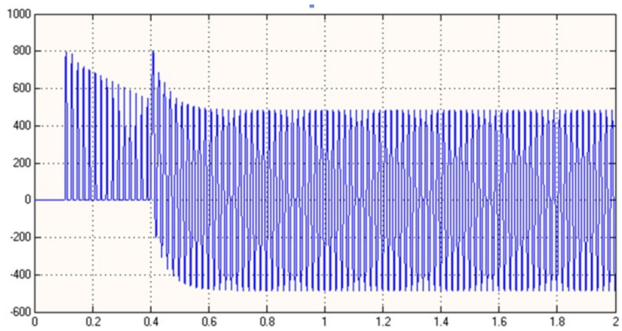

Figure 7. Ending of inrush current and starting of load current of the Case 2

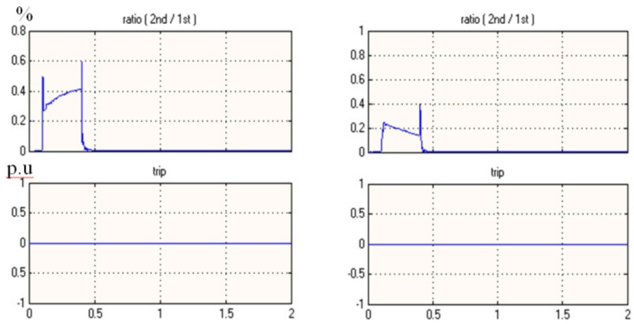


Figure 8. The ratios of the 2nd harmonic to the fundamental and the trip signals of the Case 2

### C. Case 3: Creating an Internal Fault

After switching of CB1 at 0.1 sec and CB2 at 0.4 sec, an internal fault is created at 1.5 sec at the secondary side of the power transformer by connecting the secondary side of the power transformer to the ground solidly. In this case, a significant increase of the primary current due to fault occurred inside the protected zone at 1.5 sec as shown in Figure 9.

Figure 10 illustrates the ratio of the second harmonic to the fundamental frequency which exceeded the limit of 0.7 at the instant of fault occurrence, which made a distortion to the current waveform that lead to increase the harmonic level in it. From the figure it can be noted that the secondary side only initiated a trip signal, which is enough in the final decision by sharing with the amplitude comparator to release a final trip signal that actually released from the relay.

From Figure 11 it is obvious that the relay has released a trip signal after 10.7 msec after the occurrence of the fault in order to isolate the transformer from the system.

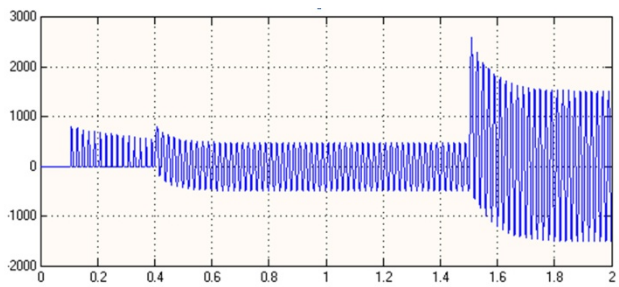

Figure 9. The increase in fault current at 1.5 sec of the Case 3

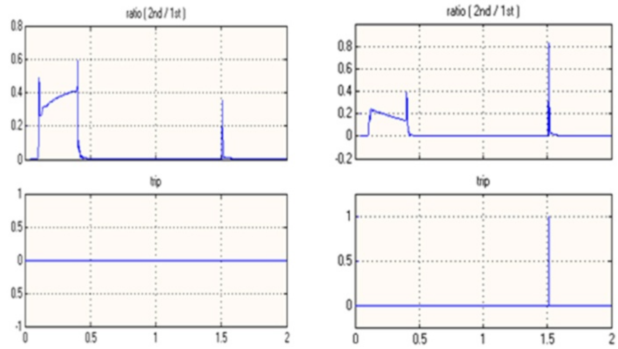


Figure 10. The ratios of the 2nd harmonic to the fundamental and the trip signals of the Case 3

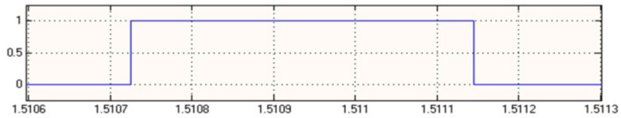

Figure 11. Released trip signal of the Case 3

### D. Case 4: Creating an External Fault

After all previous cases of testing the designed digital differential relay, it is righteous to test the security of the relay against external faults which may happen outside the protected area which may disturb the performance of the relay. Figure 12 shows the shape of currant at the primary side of the power transformer, when an external fault created at 1.5 sec and the final decision of the relay there is no trip signal is released, which insures the security of the relay.

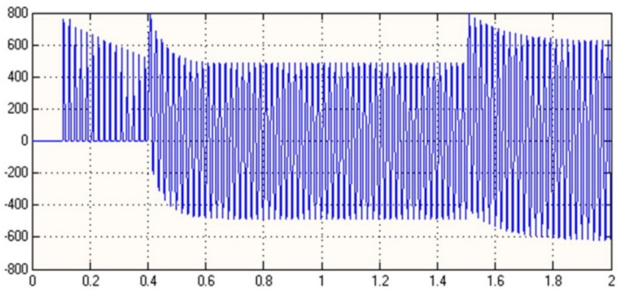

Figure 12. Creating an external fault at 1.5 sec from the beginning of simulation of the Case 4

It is obvious from the similarity of the currents, at both sides of the power transformer, there is no trip signal released from both sides. So that the final result by sharing with the amplitude comparator no trip signal is released. The behaviour of the overall system illustrates that there are no any strong effects happened to the system that can be sensitized by the relay.

## IV. CONCLUSIONS

A Matlab simulation of a small power system is presented in this research. In this simulation a new toolboxes has been added to serve the simulation of the differential relay (CTs and digital differential relay). This simulation is tested for four cases and gave good satisfactory results with a 10.7 msec speed to sensitize the internal fault in order to isolate the transformer. This time is satisfactory to ensure that the algorithm will give a true decision for the applied case whether it is a fault case or an inrush phenomenon. This usually covers the entire zone between CBs and offers a fair degree of sensitivity and security.

The size of the conventional differential relay and the complexity of its architecture, which consists of electronic components and mechanical parts that works to discriminate between the inrush current harmonics and the fault current harmonics, are decreased by using microcomputers. This reduction of complexity is done by applying the same principle of the conventional relay into a small software program easy to use and gives more accurate results with higher reliability and less cost compared with that of conventional relay. This enhancement has economical advantages such as reducing the cost of operation and construction of the relay and technical advantages such as increasing the speed of decision of the relay and easier operation.

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## BIOGRAPHY

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