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Design of Digital Differential Relay for Protection of Power Transformer

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Abstract— **Digital protection has several advantages over conventional protection scheme. For protecting costliest and vital equipment such as transformer, digital schemes have been proposed by several authors in recent past. This paper throws light on all such efforts and it will help researchers to focus on integrated efforts to protect transformer in a better and efficient way. Artificial intelligence along with signature and pattern recognition techniques gives much more useful information about happenings in and outside of transformer. Efforts are put by all concerned with fast, accurate, flexible, reliable and easy to understand scheme of protection. With the advent of soft computing methods condition monitoring with protection has become on line objective. Keeping all these state of art techniques of protection, this paper will be a useful resource. Discrimination of several faults external and internal needs digital signal processing and feature extraction as well. Many algorithms are proposed as summarized in paper.**

Keywords- digital protection; differential protection; digital differential relay.

I. INTRODUCTION

Power system development is reflected in the development of all the power system devices generators, transformers with different sizes, transmission lines and the protection equipment. Modern power transformer is one of the most vital devices of the electric power system and its protection is critical. For this reason, the protection of power transformers has taken an important consideration by the researchers. One of the most effective transformer protection methods is the differential protection algorithm. Typically, transformer protection is focused on discriminating the internal faults from the magnetizing inrush currents in the power transformers and overcoming the CTs related issues.

II. CONVENTIAL DIFFERENTIAL PROTECTION SCHEME

This scheme is based on the principle that the input power to the power transformer under normal conditions is equal to the output power. Under normal conditions, no current will flow into the differential relay current coil. Whenever a fault occurs, within the protected zone, the current balance will no longer exist, and relay contacts will close and release a trip signal to cause the certain circuit breakers (CBs) to operate in order to disconnect the faulty equipment/part. The differential relay compares the primary and secondary side currents of the power transformer. Current transformers (CTs) are used to reduce the amount of currents in such a way their secondary side currents are equal. Fig. 1 shows the differential relay in its simplest form. The polarity of CTs is such as to make the current circulate normally without going through the relay, during normal load conditions and external faults ratings are selected carefully to be matched with the power transformer current ratings to which they are connected so as the CTs secondary side currents are equal. However, the problem is that the CTs ratios available in the market have standard ratings. They are not available exactly as the desired ratings. Therefore, the primary ratings of the CTs are usually limited to those of the available standard ratio CTs. Commonly the primary side of the current transformer has only one turn (1) and the secondary side has many turns depending on the transformation ratio (N) of the CT, which is selected to match the ratings of the power transformer. Since the transformation ratio of transformers is the ratio between the numbers of turns in the primary side to the number of the turns in the secondary side. Therefore, the turn ratio of the primary current transformer is $1/N_1$and the turn ratio of the secondary side current transformer is $1/N_2$. The secondary current of the CT located in the primary side of the power transformer.

III. DIFFERENT CURRENTS IN TRANSFORMER

In this paper, the different systems are examined for foresee the determination of diabetes. Utilizing the information mining system the medicinal services administration predicts the illness and determination of the diabetes and after that the medicinal services administration can caution the individual in regards to diabetes based upon this forecast. The Principal Component Investigation (PCA) is likewise the system utilized for the examination. The PCA is the component extraction system has more act upon on the exactness of characterization systems. In any case, when the PCA joined with the Neural Networks for characterization accomplished the best grouping exactness and the PCA performs preferred for non-diabetic examples over the diabetic examples when consolidated with Neural Networks. Grouping pace of ANFIS is not superior to the Neural Systems.

A. *Magnetizing Inrush*

In an electrical system, energizing a transformer can generate inrush current. Although the magnitude of this current is only 1–2% of the transformer rated current under the steady state operating conditions, it may become as high as several ten times the rated current when transformers are energized. Because of slow attenuation of this transient, its effect may persist for several seconds before the steady state is reached. These transients may cause unnecessary tripping of relays, so it affects the reliability of the system.

B. External System Short Circuits

External system short circuits are system faults that occur outside of the transformer protection zone. Because these faults cause large transformer currents, they can damage transformer windings.

C. *Internal Short Circuits*

Internal faults are faults that occur within the transformer protection zone. Transformer internal faults can be divided into two classifications: internal short circuit faults and internal incipient faults. Internal short circuit faults are generally turn-to-turn short circuits or turn to earth short circuits in transformer windings. These faults occur suddenly and usually require fast action by protection devices to disconnect the transformer from the electric system.

IV. DIGIAL DIFFERENTIAL PROTECTION

Many digital algorithms have been used so far after the invention of the computer. These algorithms do the same job with different accuracy and speed. The acceptable speed according to IEEE standard for transformer protection is 100 msec. All modern algorithms are faster than this IEEE standard. Nowadays, there are some algorithms performs their function in less than 10 msec. In this chapter, a fast algorithm is introduced. Its speed is in the range of 1 to 15 msec. This algorithm is based on the Fast Fourier algorithm (FFT). This algorithm is not new, however, significant changes has been introduced to make it much faster.

The proposed digital differential relay is designed using a simulation technique in Matlab Simulink environment. The design is implemented to protect the power transformer against internal faults and prevent interruption due to inrush currents.

This algorithm is built on the principle of harmonic-current restraint, where the magnetizing-inrush current is characterized by large harmonic components content that are not noticeably present in fault currents. Due to the saturated condition of the transformer iron, the waveform of the inrush current is highly distorted.

The amplitude of the harmonics, compared with the fundamental is somewhere between 30% to 60% and the third harmonic 10% to 30%. The other harmonics are progressively less [3] [6], [8]. Fast Fourier Transform (FFT) is used to implement this approach. In general, any periodic signal *f*(t) can be decomposed to its sine and cosine components as follows:

$$f(t) = \frac{a0}{2} + \sum_{k=1}^{\infty} Ck\cos(kwt) + Sk\sin(kwt)$$

Where: is the DC component of the f (t), and C_k, Cs are the cosine and sine coefficients of the frequencies present in *f*(t), respectively. The discrete forms of the coefficients C_k, C_s are expressed in the following equations

$$Ck = \frac{2}{N} + \sum_{n=1}^{N-1} x(n)\cos\left(\frac{2kwt}{N}\right)$$

$$Sk = \frac{2}{N} + \sum_{n=1}^{N-1} x(n)\sin\left(\frac{2kwt}{N}\right)$$

The Fourier harmonic coefficients can be expressed as [13]:

$$Fk = \sqrt{Sk^2 + Ck^2}$$

Where: F_k is the K^{th} harmonic coefficient for k = 1, 2,...,N and *x*(n) is the signal *f*(t) in its discrete form. The FFT produces exactly the same results as the DFT; however, the FFT is much faster than DFT, where the speed of calculation is the main factor in this process [8-11].

Fig 1 illustrates the flow chart of the designed digital Fourier Transform based logic technique algorithm. In this algorithm the output currents of the CT_S undergo over two analysis processes, amplitude comparison process and harmonic content calculation process. The amplitude comparison between the RMS values of the CT_S output currents ($|Id_1 - Id_2|$) is in the left hand side of the flowchart, and the harmonic calculation is in the right hand side of the flowchart. The software is implemented according to the following steps [10-12]:

Step 1. Reading data from the CT_S.

Step 2. Data calculation, which is given as follows; For the amplitude calculation, if the absolute difference ($|Id_1 - Id_1|$) between the CT_S output currents is greater than zero the logic (1) takes place, which indicates the case of an inrush current or an internal fault. Otherwise, the logic (0) takes place, which indicates a detection of an external fault.

(0) In the meantime, the harmonic calculation is performed. If the percentage value of the second harmonic amplitude is in the range of (0.3 to 0.6) of the fundamental component amplitude, then the logic (0) occurs, that means recognition of inrush current. Otherwise, the logic (1) takes place, which indicates a detection of an internal or external fault.

Step 3.Taking the final decision:

If the logic cases received from both cases (a & b) in step two are both (1), that indicates a detection of an internal fault. Then a trip signal is released to stop the simulation. For the other logic options of (0,1) means an external fault, (1,0) means an inrush current, or (0,0) indicate an occurrence of an inrush current or an external fault, and the simulation goes back to step two to start the calculation again for the next sample.

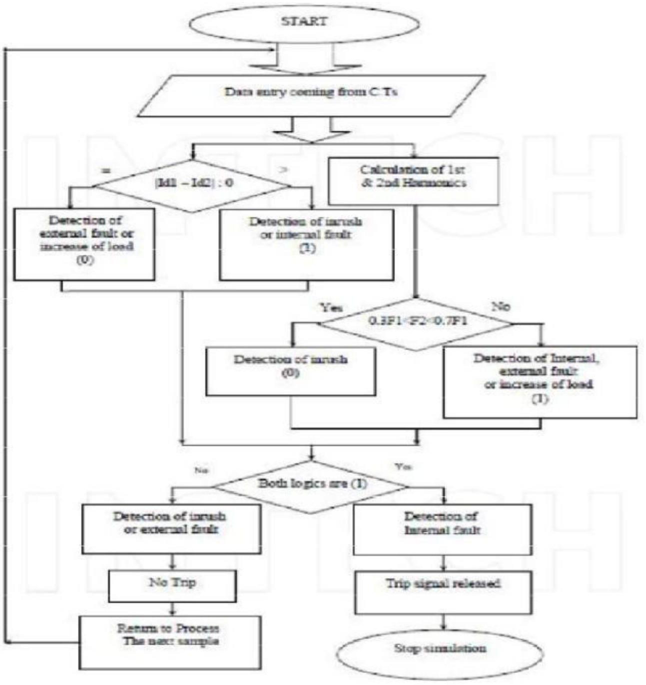

Figure 1: Flow Chart of the Digital Differential Relay Scheme

V. IMPLEMENTATION OF THE DIGITAL DIFFERENTIAL PROTECTION USING MATLAB

This implementation is done using Matlab/Simulink environment. Figure 2 shows the simulated power system built in Matlab/Simulink environment. In which a three phase, 50MVA, 50Hz, (115/23) kV, Y/Y power transformer is used in this system.

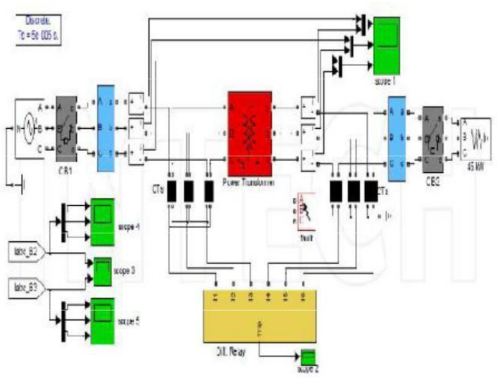

Figure 2: Matlab/Simulink Model of the proposed system

VI. RESULTS

The results and discussions

The results will be given for different cases:

Case 1: magnetizing inrush current,

Case 2: Three phase to ground fault at loaded transformer,

Case 3: Phase A to ground external fault at loaded transformer,

Other cases of different types of faults and inrush currents such as single line to ground fault, line-to-line fault, line to line to ground fault and three phase fault in both cases loaded and unloaded transformer are illustrated.

Case 1: Magnetizing inrush current:

In this section of simulation, when the primary side CB1 is closed at 0.1 sec, only the inrush current flows in the primary circuit of the power transformer and no current passes through the power transformer to the secondary side as shown in Fig. 3. The value of the 2nd harmonic is higher than 0.3 of the fundamental component.

In this case the harmonic calculation part released logic (0) but the amplitude comparator that the differential current is equal to the inrush current, where both curves are drown over each other, then the amplitude comparator release logic (1). For this logic coordination (0,1) no trip signal is released.

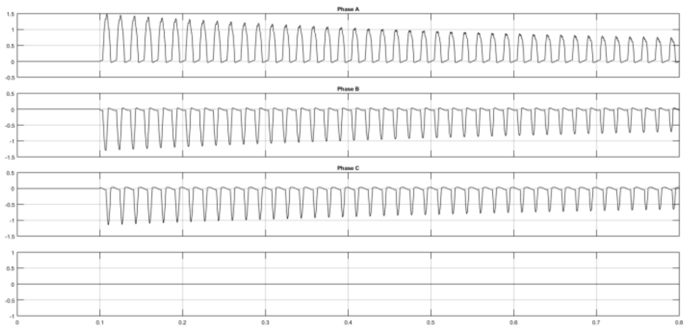

Figure 3: Inrush currents waveforms of the three phases at the primary side of the power transformer

Case 2: Three phase to ground fault at loaded transformer:

In this section, a three phase to ground fault is created to test the security of the algorithm. After the switching of CB1 at 0.1sec, an internal fault is created at 0.5 sec at the secondary side of the power transformer by connecting the three phases A, B and C of the secondary side of the power transformer to the ground. In this case, a significant increase of the primary current takes place due to the fault occurrence inside the protected zone at 0.5 sec as shown in Fig. 4. The relay detected this increase using the harmonic and amplitude comparators and realized it as an internal fault. Consequently the transformer is isolated from the grid. Also it is obvious that the relay has released a trip signal after 0.57 msec after the occurrence of the fault, which can be considered as a very good speed to isolate the transformer. After the occurrence of the fault at time 0.5 sec, the value of the 2^{nd}harmonic increased during the transient time and then decreased rapidly to a value lower than 0.3 of the fundamental component once the steady state is achieved. Accordingly, the harmonic calculation part released logic (1). The result of the amplitude comparator the value of the differential current is no longer

equal to zero. Accordingly the amplitude comparator released logic
(1). Therefore, for this logic coordination (1,1) a trip signal is released in order to isolate the power transformer from the grid.

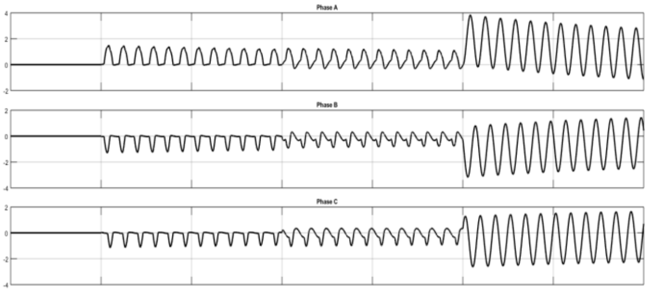

Figure 4:Increase of phase A current due to the occurrence of the fault at 0.5 sec for loaded

VII. SUMMARY OF TESTED RESULTS

Case type	Relay response	Trip signal release time (m sec)
Internal Fault	*Trip*	*Trip signal*
External Fault	*Restrain*	*No Trip signal*
Inrush Current	*Restrain*	*No Trip signal*

CONCLUSION

This paper deals with the implementation and simulation of a small power system with a differential protection for the power transformer. The implementation is shown in step by step. This simulation is tested for various cases and it gives satisfactory results. It is found that by FFT analysis we can have fast trip signal with proper discrimination of various cases for a power transformer.

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