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전력용변압기보호를 위한 개선된 수치계전기법

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Advanced Numerical Relaying for Power Transformer Protection

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Abstract - The second harmonic component could be decreased by magnetizing inrush when there have been changes to the material of the iron core or its design methodology. The higher the capacitance of the high voltage status and underground distribution, the more the differential current includes the second harmonic during the occurrence of an internal fault. Therefore, the conventional second harmonic-restrained RDR needs modification. This paper describes an advanced numerical algorithm that utilizes terminal voltage, differential current, harmonics, harmonic ratio, and flux-differential current slope. Based on the results of testing with WatATP99 simulation data, the proposed algorithm was proven to be faster and more reliable.

1. Introduction

The commonly encountered transformer protection arrangement is based on the differential current principle. The digital protective relaying scheme based on the harmonic-restrained ratio differential relaying (RDR) for the power transformer is most widely used. The second harmonic-restrained RDR is based on the fact that the 2nd harmonic is usually predominant under all energization conditions.[1] However, the 2nd harmonic component could be decreased by inrush when there have been changes to the material of the iron core or its design methodology. The higher the capacitance of the high voltage status and underground distribution, the more the differential current includes the 2nd harmonic component during the occurrence of an internal fault. Therefore, the conventional harmonic-restrained methods must be modified. Recently, in order to overcome such problems, several new approaches utilizing AI technique have been developed.[2-4] The DWT-based algorithm has been reported.[2] Seung-Jae Lee et al. also proposed voltage-current trend-based protective relaying algorithm.[3] Most of these approaches are liable to false operation during magnetizing inrush with low 2nd harmonic component and internal faults with high 2nd harmonic component. This paper proposes an advanced numerical relaying by trend of voltage and differential current, harmonics, and flux-differential current slope characteristics. To evaluate performance of the proposed algorithm, we have made comparative studies of the conventional RDR, the fuzzy logic-based relaying and the DWT-based relaying.[4] The paper illustrates the constructed power system model including power transformer, utilizing the WatATP99 software.

2. Advanced Numerical Relaying

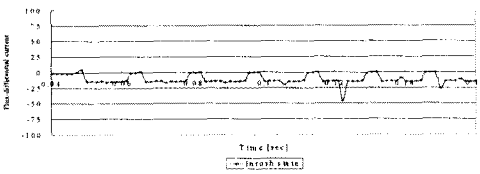
2.1 Flux-Differential Current Slope

Flux-current characteristic basically uses the flux-current relation of the transformer to obtain the restraint function for blocking mal-operation of the relay under the transformer transient state.[5] However, residual flux in the core of the transformer is not zero. Actually, we can determine by its slope than flux-differential current itself in the flux-differential current plain. That is to say, the flux-differential current slope $d\phi_k/di_k$ at the kth sample is defined by

$$\left(\frac{d\phi}{di_d}\right)_k \cong \frac{\phi_k - \phi_{k-1}}{i_{p.k} - i_{p.k-1}} = \frac{\left\{\frac{\Delta t}{2}\left(v_{p.k} + v_{p.k-1}\right) - L_p\left(i_{p.k} - i_{p.k-1}\right)\right\}}{\left(i_{p.k} - i_{s.k}\right) - \left(i_{p.k-1} - i_{s.k-1}\right)}$$

Where subscripts p and s represent primary side and secondary side of the power transformer, Δt is sampling interval, i_d is differential current, ϕ is flux, and L_p is the leakage inductance of the primary winding at kth sample.

Fig. 1 is plotted by calculating the flux-differential current slope with relaying signals obtained from WatATP99 simulation by the selected transformer in this paper. X and Y axes indicate time and flux-differential current slope, respectively. We can see that calculated values arrive close to zero in case of steady state, the values fluctuate between approximately -15 to 0 during energization of the transformer, while the values show around -15 under internal fault. From the transition characteristics of the calculated flux-differential current slope, it may be kept distinct about fault conditions as well as magnetizing inrush and steady state.



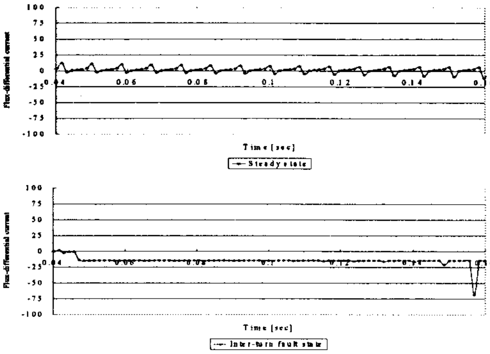


Fig. 1 Transition characteristics of flux-differential current slope

Fig. 2 illustrates the flow chart of proposed relaying algorithm with trend of voltage and differential current, harmonic analysis carried out using DFT, and the flux-differential current slope characteristic. It consists of initialization, data input, computational data, fault discrimination between disturbance and internal faults, and trip signal issue. I-CNT and F-CNT indicate inrush counter and fault counter, respectively. The several computed values in this study are used to clear fault detection by comparison with the predefined threshold value.

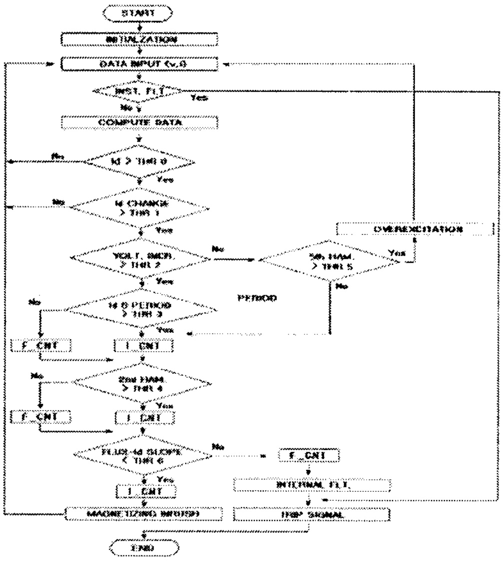


Fig. 2 Flow chart of a proposed numerical relaying

3. Testing the Relaying

For an evaluation of the proposed relaying algorithm, we used the transformer inrush currents, internal fault currents, and voltage signals. The 3-phase, 45/60MVA, 154/23KV transformer is simulated by the saturable transformer model and the BCTRAN routine.[5,6] This section describes the extraordinary points proposed in particular cases. The specific waveforms are generated by the means of addition or removal prescribed 2nd harmonic component by the MS Excel program from WatATP99 simulation data.[7]

Fig. 3 shows A phase current signal in the primary side during inrush with low 2nd frequency ratio. Fig. 4 indicates ratio of second frequency over fundamental frequency during inrush. X and Y axes indicate time and magnitude of F1/F2, respectively. During the modified inrush condition, the ratio of 2nd frequency component over 1st frequency component using DFT filter extraction is nearly 10 %.

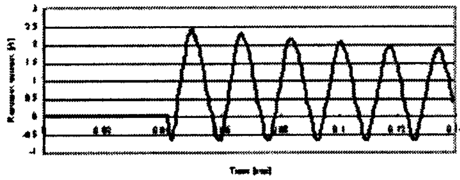


Fig. 3 A phase current signal in primary side during inrush with low 2nd frequency ratio

Fig. 5 presents the results of fault discrimination using the proposed algorithm and the comparative algorithm, when energizing with low 2nd frequency ratio. As seen in Fig. 5, the proposed algorithm operates well while the conventional RDR mal-operates.

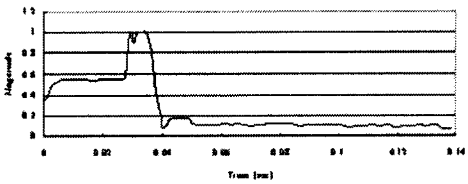


Fig. 4 Ratio of 2nd frequency over 1st frequency during the specific inrush

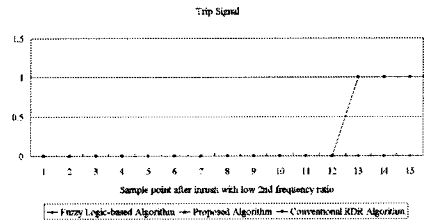


Fig. 5 Fault discriminant during inrush with low 2nd frequency ratio

Fig. 6 shows A phase current signal in the primary side under terminal to ground fault with high 2nd frequency ratio at about 47.2ms. Fig. 7 represents nearly 35% on the ratio of 2nd frequency component over 1st frequency component. Fig. 7 illustrates the results of fault discrimination by the proposed algorithm, the fuzzy algorithm, and the conventional RDR. As shown in Fig. 7, the conventional RDR mal-operates and it means blocking the trip signal. Relay issues the trip signal in case of the proposed algorithm. These results of Figs. 5 and 8 show the difference between the algorithm suggested in this paper and the conventional algorithm.

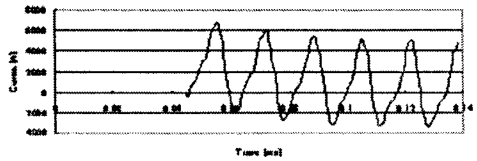


Fig. 6 A phase current signal in primary side under terminal to ground fault with high 2nd frequency ratio

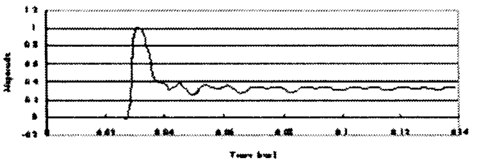


Fig. 7 Ratio of 2nd frequency over 1st frequency under the specific terminal to ground fault

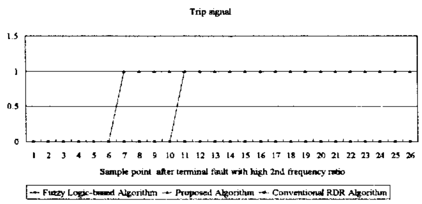


Fig. 8 Fault discriminant under terminal to ground fault with high 2nd frequency ratio

4. Conclusions

In this paper, an advanced protective algorithm for power transformer is developed. The proposed numeric algorithm made use of rms value of terminal voltage, instantaneous differential current, harmonics ratio, and flux-differential current slope characteristic for overcoming the limits of conventional relaying. The proposed algorithm of utilizing the Turbo C programming language could help solve problems related to power transformer protection by examining case studies of data collected by the WatATP99 simulation software and the MS-Excel. Below are some results.

(1) This study proposed advanced algorithm that can quickly distinguish between internal faults and magnetizing inrush of the power transformer.

(2) The proposed algorithm imported the flux-differential slope characteristic, thus improving and solving the previously existing problems with the conventional 2nd harmonic-restrained RDR algorithm.

(3) The proposed technique does not solely rely on the inclusion ratio of the 2nd harmonic component when determining the existence of inrush. Because of this, it can prevent mal-operation of the RDR by improvements in the iron core material and power system environment changes.

(4) The proposed algorithm enables magnetizing inrush detection within nearly 1 period and it can detect internal faults within a period of 0.5.

(5) When compared with the fuzzy relaying, the DWT relaying, and conventional RDR relaying algorithm, this new advanced numerical algorithm excelled not only in relay operation time, but also in other comparison criteria.

ACKNOWLEDGEMENT

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