Transformer Differential Protection Using Matched Wavelets

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by

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Chapter 5

Conclusion and Future Scope

5.1 Conclusions

Literature survey on differential protection of power transformer and matched wavelets was done in the first chapter. Various detection methods based on Harmonic Restraint, Wave Shape, Fuzzy Logic, ANN, Decision Tree, and Wavelet Analysis were classified and discussed. Literatures based on hardware implementations of differential protection techniques were also discussed. The motivation, research gap, objectives, outline and major contributions of the thesis are described in the first chapter.

In the second chapter, design of matched wavelets for inrush and fault signals has been presented. The specific wavelets designed are tested for their efficacy vis-a-vis the standard mother wavelets. Comparison with standard wavelets clearly established that the developed matched wavelets are relatively better in discriminating between inrush and fault waveforms. The design of matched wavelets specific to inrush and fault waveforms for differential protection is major contribution of this chapter. The matching was done in least square sense. The DE algorithm was used to get an optimal matching wavelets. In course of finding matched wavelet we came across the fact that smoothness of matched wavelets and application for which matched wavelet is designed are independent to each other. This means that the designed matched wavelet for a desired signal can be smooth depending on the smoothening constraints applied. However, if the obtained matched wavelet is not smooth or oscillatory in nature even then it will retain all the qualities of a wavelet. The theory of matched wavelet and its mathematical relevance with matched filter is also presented. Finding matched wavelet for a specified signal is formulated as an optimization problem and DE is used to obtain optimal matched wavelet. The matched wavelets obtained for standard wavelet signals are discussed in this chapter to verify the algorithm used for finding matched wavelet. Also, the performance of matched inrush wavelet obtained for inrush signal is compared with the performance of standard wavelets in detection of inrush signal. The results of comparison of matched wavelets to that of standard wavelets used in literature are discussed in this chapter. It was established that the matched wavelet outperformed the standard wavelets in detecting the inrush and fault waveform.

Chapter 3 contributes a new differential protection scheme based on *independent* detection of fault and inrush waveforms. In this scheme the fault and the inrush are detected separately and simultaneously. The independent detection of fault and inrush waveforms is made possible through the use of filters designed on the basis of matched fault wavelet and inrush wavelet respectively. The optimal matched wavelets developed are tested for *Inrush Processing* and *Fault Processing*.

The cause of occurrence of various operating conditions such as magnetizing inrush, over fluxing, sympathetic inrush, internal/in-zone faults, external faults of transformer were discussed in Chapter 3. CT saturation effects have strong impact on signals corresponding to various operating conditions. The detailed analysis for CT saturation was presented in the chapter. The proposed differential protection scheme is tested on different waveforms obtained at different switching angles ranging from 0 to 180 degrees under various operating conditions including CT saturation effects. To test the generality of the scheme the testing waveforms are taken from MATLAB and PSCAD/EMTDC models. Transformer with rating 25 MVA is designed on MATLAB platform. Transformer with ratings 315 MVA and 200 MVA are designed on PSCAD/EMTDC platform. Also, the robustness against noise of the proposed scheme is evaluated by adding ±5% uniformly distributed noise to the obtained waveforms. The proposed scheme successfully detects and discriminate between the inrush and fault signals. It was observed that, for the cases considered, the cycles required to detect a *phase-to-phase fault* is 0.1 cycle, where as, to detect the sympathetic inrush the system can take up to 0.153 cycle. This situation suggests that there could be practical scenarios where fault could be detected faster than the inrush. Thus, the idea of independent detection of fault and inrush is advantageous over the traditional scheme.

The main contribution of Chapter 4 is the development of hardware for the proposed differential protection scheme. The inrush-filter and fault-filter based on matched wavelets developed and tested in Chapter 2 and 3 were designed on Xilinx FPGA boards (filter-board). The results obtained from filters implemented on FPGA board matched quite well with the simulation results and were found to be within the permissible limits. The differential current waveforms are applied as inputs for the filter unit. Therefore, differential waveforms obtained from the simulation are recorded on FPGA board (waveform-board) to test the filter unit. Two FPGA boards are used, one each for the development of differential input signal and implementing filter unit. Nexys A7 Xilinx board is used for creating differential signals. Nexys video Xilinx board is used for implementing filter units. Furthermore, the proposed method was implemented on a physical transformer in real-time to establish the efficacy of method proposed in the thesis. It was demonstrated that the matched wavelets can be successfully implemented and used in the present state-of-art technologies.

5.2 Future Scope

Differential protection schemes are going to face several challenges due to new types of loads and sources feeding the systems. The newer differential protection systems will have to cope with presence of high level of harmonics in supply and loads appearing in the systems. The fault waveform characteristics and the generations from renewable sources may affect the fault differential waveform. A fresh look at the development of differential protection may be required. The work of matched wavelet based fault detection may easily be extended to the situation where signature based fault analysis may be required. These situations are high resistance fault protection, distance protection, and combined differential transformer protection of transformer and generator units.