Power Quality Disturbances and Protective Relays on Transmission Lines

Shaik Sharif[1], N. Asha Latha[2], Shaik Dawood[3]
[1]Asst.Professor, Dept. of EEE, Nimra Women's College of Engineering, A.P., India.
[2]Asst.Professor, Dept. of EEE, Nimra Women's College of Engineering, A.P., India.
[3]Asst.Professor, Dept. of EEE, Nimra College of Engineering & Technology, A.P., India.

Abstract - **Power quality concerns the effect of voltage disturbances on end-user equipment and of current disturbances on network components. Power system protection concerns the detection of faults in the system from measured voltages and currents. However, non-fault voltage and current disturbances may lead to the inadvertent detection of a fault in the same way as voltage disturbances may lead to the tripping of end-user equipment. Starting from the principles (algorithms) of the relays, a quantification approach is developed to assess the disturbance impact on the relays. The quantification is based on the relay response after processing the disturbance signals by relay filters. This makes it possible to quantify the disturbance impact by the consequences caused by the disturbances, other than by the signal waveforms of the disturbances. Power transmission lines protection is one of the most important concerns for power utilities. Different types of faults occur on Transmission Line. From the transient phenomena, faults on transmission lines need to be detected, classified, located accurately, and cleared as fast as possible. Identification and classification of faults on transmission line are essential for relaying decision and auto-reclosing requirements. This dissertation presents a novel Wavelet-Fuzzy combined approach for digital relaying. An algorithm based on wavelet multi-resolution analysis (MRA) is used for classification of transmission faults for quick restoration of power supply and for improving the transient stability.**

Keywords - **Multi-Resolution Analysis (MRA), Fuzzy Inference System (FIS).**

I. INTRODUCTION

Power system disturbances are, in the sense of source, the result of switching or operation of power system components; or in the sense of measurement, the transient or steady-state voltage and current; or in the sense of impact on power systems, the disturbances that degrade the performance of device, equipment or system. The presence of power system disturbances reflects the power quality in a system. The term power quality was first introduced in late 1960's [1][2][3], almost a century after the first power system was put in service. It became in common use twenty years later. Before that time, it did not attract too much attention mainly because of two reasons. One is that in the past there were much fewer power system components that could generate power system disturbances. The other is that in the past there were much fewer power system components that were sensitive to power system disturbances. Obviously these two factors are mutually linked [4]. With the development in electronics technology, more and more power system components are equipped with electronic devices. The introduction of electronic devices enables much more flexibility for system and component operation, regulation and protection. While the improvement on the functions is enormous, its side effect is also inevitable: the presence of electronic device in the systems, together with the flexible component operation mode brought by electronic device, will lead to both transient and steady-state problems in power systems. Such power quality disturbances not only exist locally, but also propagate to other parts of the power system. On the other hand the electronic device itself is much more vulnerable to such power quality disturbances than the classical power system components. In a word, the main source of power quality disturbances today is the application of electronic technology as well as the change of operation mode benefiting from the application of such techniques.

Protective relays play a critical role in the operation of the electrical power system. The protective relays are designed to take action when abnormal conditions occur on the power system. Elaborate protection schemes have been developed to detect these various conditions using current and voltage measurements through current transformers and potential transformers. Microprocessor-based relays offer many advantages over conventional schemes. Fault locating has become a standard feature in nearly all microprocessors-based relays. Wavelet transforms are better suited for the analysis of certain types of transient waveforms than the other transforms approach. This thesis presents a descriptive overview of the wavelet transform applications in power systems. The aim of this chapter is to provide a descriptive overview of the wavelet transform applications in power systems to those who are novel in the study of this subject. Wavelet transform (WT) has been introduced rather recently in mathematics, even though the essential ideas that lead to this development have been around for a longer period of time. It is a linear transformation much like the Fourier transforms, however it allows time localization of different frequency components of a given signal. Windowed Fourier transforms (STFT) also windowing function is a limitation.

Several works have been developed in many areas with the aim of this tool, specially, in the last ten years have been met the potential benefits of applying WT to power systems due to, among other, the interest in analyzing and processing the voltage-current signals in order to make a real time identification of transients in a fast and accurate way. In most of the power system relaying algorithms, the first step always involves fault detection and classification. The information provided by this step is essential for the fault location algorithm. Most of the present relaying algorithm use sharp variation values of the three-phase currents to detect and classify the fault. If several successive sharp values are larger than a specified threshold, a fault is said to have occurred. By the comparison of the sharp variation values of three-phase currents, the fault type can be identified further.

II. BACKGROUND

Power system disturbances are of various types related to their different sources. currents, dynamic operations as well as faults. The components that suffer from such disturbances are also of various types. Among the affected components, the protective relay is an important device for the safe and reliable operation of power systems. Protective relays play no role when the operation of power systems is stable and normal. They are designed to operate when there are faults involved in the systems. The direct consequence of relay operation is system component cutoff, which definitely affect the operation of the system. Therefore either fail-to-trip or a mal-trip can lead to considerable economic losses. In the former case, a fail-to-trip makes the fault-involved components remain at critical conditions too long, damaging the components either in short-term or in long-term. In the latter case, a mal-trip cuts off components that are under healthy operation, possibly causing direct economic losses to customers.

Therefore two characteristics are important for protective relays: sensibility (or dependability in a more formal way) when there is a fault, and immunity (or security in a more formal way) when there is anything other than faults. The former tells how reliable a relay is when it should operate, while the latter tells how robust a relay is when it should not operate. In this sense, protective relays should not react to any power system disturbance. However, most protective relays are designed to deal with the situation when the voltage and current signals are steady-state sinusoidal waveforms. In case of power system disturbances, whether protective relays will experience a mal-trip is dependent on the type of the disturbance as well as the structure of the relay. Although some new generation relays possess ability to be adaptive to some of the external changes, this cannot guarantee complete immunity from the disturbances because the disturbance conditions are far more than one can expect. Also with the possible higher requirement on fault-clearing time in the future, faster relays will be needed. A faster relay means a shorter decision-making time, which implies a higher possibility of mal-trip due to inadequate information obtained by the relay within such short time.

2.1 Wavelets Overview

The fundamental idea behind wavelets is to analyze according to scale. Indeed, some researchers in the wavelet field feel that, by using wavelets, one is adopting a whole new mindset or perspective in processing data. Wavelets are functions that satisfy certain mathematical requirements and are used in representing data or other functions. This idea is not new. Approximation using superposition of functions has existed since the early 1800's, when Joseph Fourier discovered that he could superpose sines and cosines to represent other functions. However, in wavelet analysis, the scale that uses to look at data plays a special role. Wavelet algorithms process data at different scales or resolutions. If look at a signal with a large “window”, would notice gross features. Similarly, a signal with a small “window”, we would notice small features. The result in wavelet analysis is to see both the forest and the trees, so to speak. This makes wavelets interesting and useful. For many decades, scientists have wanted more appropriate functions than the sines and cosines which comprise the bases of Fourier analysis, to approximate choppy signals. By their definition, these functions are non-local (and stretch out to infinity). They therefore do a very poor job in approximating sharp spikes. But with wavelet analysis, I can use approximating functions that are contained neatly infinite domains. Wavelets are well-suited for approximating data with sharp discontinuities.

The wavelet analysis procedure is to adopt a wavelet prototype function, called an analyzing wavelet or mother wavelet. Temporal analysis is performed with a contracted, high-frequency version of the prototype wavelet, while frequency analysis is performed with a dilated, low-frequency version of the same wavelet. Because the original signal or function can be represented in terms of a wavelet expansion (using coefficients in a linear combination of the wavelet functions), data operations can be performed using just the corresponding wavelet coefficients. And if you further choose the best wavelets adapted to your data, or truncate the coefficients below a threshold, your data is sparsely represented. This sparse coding makes wavelets an excellent tool in the field of data compression.

2.2 Fourier Analysis

Fourier's representation of functions as a superposition of sines and cosines has become ubiquitous for both the analytic and numerical solution of differential equations and for the analysis and treatment of communication signals. Fourier and wavelet analysis have some very strong links.

2.3 Fourier Transforms

The Fourier transform’s utility lies in its ability to analyze a signal in the time domain for its frequency content. The transform works by first translating a function in the time domain into a function in the frequency domain.

The signal can then be analyzed for its frequency content because the Fourier coefficients of the transformed function represent the contribution of each sine and cosine function at each frequency. An inverse Fourier transform does just what we’d expect; transform data from the frequency domain into the time domain.

2.4 Wavelet Transforms Versus Fourier Transforms

Similarities between Fourier and Wavelet Transform:

The fast Fourier transform (FFT) and the discrete wavelet transform (DWT) are both linear operations that generate a data structure that contains $\log_2 n$ segments of various lengths, usually filling and transforming it into a different data vector of length 2^n.

The mathematical properties of the matrices involved in the transforms are similar as well. The inverse transform matrix for both the FFT and the DWT is the transpose of the original. As a result, both transforms can be viewed as a rotation in function space to a different domain.

For the FFT, this new domain contains basis functions that are sines and cosines. For the wavelet transform, this new domain contains more complicated basis functions called wavelets, mother wavelets, or analyzing wavelets.

Both transforms have another similarity. The basis functions are localized in frequency, making mathematical tools such as power spectra (how much power is contained in a frequency interval) and scalegrams (to be defined later) useful at picking out frequencies and calculating power distributions.

Dissimilarities between Fourier and Wavelet Transforms:

The most interesting dissimilarity between these two kinds of transforms is that individual wavelet functions are *localized in space*. Fourier sine and cosine functions are not. This localization feature, along with wavelets' localization of frequency, makes many functions and operators using wavelets "sparse" when transformed into the wavelet domain. This sparseness, in turn, results in a number of useful applications such as data compression, detecting features in images, and removing noise from time series.

One way to see the time-frequency resolution differences between the Fourier transform and the wavelet transform is to look at the basis function coverage of the time-frequency plane. Figure1 shows a windowed Fourier transform, where the window is simply a square wave. The square wave window truncates the sine or cosine function to fit a window of a particular width. Because a single window is used for all frequencies in the WFT, the resolution of the analysis is the same at all locations in the time-frequency plane.

3. PRINCIPLES OF DIGITAL RELAYS IN POWER SYSTEMS

3.1 Structure of digital relays

A digital relay consists of the following main parts:

- Processor
- Analog input system
- Digital output system
- Independent power supply

Fig. 3.1.1 shows the block diagram of a digital relay

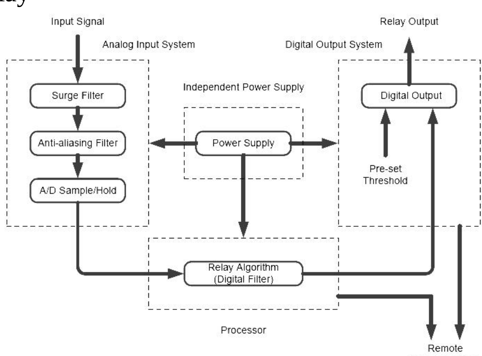

Figure 3.1.1 Block diagram of digital relay

The main difference in principle between digital relays and conventional relays is in the way of input signal processing. The input signals, which come from CTs or PTs, are always analog signals. They are directly imposed to the electromagnetic winding or electronic circuits in conventional (electromechanical and static) relays. In the case of digital relays, the input signals are converted into digital signals before being processed. In the analog input system, a surge filter is used to suppress the large inrush in the input signals, for the safety of the digital relay.

3.2 Digital algorithms for single-input relays

A "single-input relay" is a relay that operates on only one input signal. Many relays, which have either voltage or current as their inputs, are single-input relays. The philosophy of digital algorithms for such relays is to remove the unwanted components as much as possible so as to extract the fundamental component from the input signals. The fundamental component is then (possibly after further processing) compared with a threshold. Several algorithms are available for this purpose. The most common ones are Discrete Fourier Transform (DFT), Least Squares (LS), Root Mean Square (RMS), Walsh, and Kalman algorithms.

3.2.1 Discrete Fourier algorithm (DFT)

The main concept of the Fourier algorithm is that any signal can be regarded as a combination of periodic components, provided that it meets the Dirichlet conditions, i.e. finite discontinuous points, limited extremes and limited integration value within any period . The deduction of the Fourier algorithm is based on the following two assumptions:

1. Measurement errors have constant covariance and are independent from sample to sample.
2. Any dc offset term is eliminated (e.g. by an analog filter or by means of software)

IV. PROBLEM FORMULATION AND SOLUTION TECHNIQUES FOR TRANSMISSION LINE FAULT CLASSIFICATION AND LOCATION

The single diagram of the power system model considered for simulation study is shown in Fig 3.1. The line parameters and other relevant data for the power system model are as follows.

Distributed model of transmission line is considered for simulation.

4.1 Transmission Line Fed from One End

Line length = 100 km

Source voltage (v_s) = 400 kV

Positive, Negative sequence line parameters:

R = 2.34 Ω, L = 95.10 mH, C = 1.24 μF,

Zero sequence line parameters:

R = 38.85 Ω, L = 325.08 mH, C = 0.845 μF.

Source impedance (Zs):

Positive, negative sequence impedance = (0.45+j5) Ω/phase

Zero sequence impedance = 1.5 * positive sequence impedance

Load parameters:

Active power: 500 MW,

Reactive power (inductive): 20 Mvar.

4.2 Fault Signal Analysis Using Wavelets

The high frequency information can be extracted from the original signal with the help of MRA. For the faulted power system, this high frequency information may contain useful fault signatures. The objective of this thesis is to detect, classify, and locate the fault from the detail signals of the MRA output.

Several parameters must be specified in this problem, viz. the sampling frequency, the number of stages of the MRA filter banks and the wavelet type. In order to diminish the computation burden of the algorithm, the sampling frequency should not be too high. Meanwhile, it should be high enough to capture the characteristic information of the fault. In this thesis, a sampling frequency of 12.5 KHz and a single-stage MRA filter bank are selected. Simulation results show that, in this case, the first-stage MRA detail signal contains enough information for the fault detection and classification.

Another important parameter is the wavelet type. After the examination of several kinds of wavelet, the Daubechies D-4 wavelet is proved to have little computational burden as well as good performance, where both the low-pass and band-pass filters *h(n)* and *g(n)* have only four coefficients

V. CONCLUSION

The main contributions in this work consist of two parts: quantification of component switching in the viewpoint of protective relays; analysis of frequency deviation impact on protective relays. Quantification of component switching in the viewpoint of protective relays.

A new approach is proposed to quantify the severity of component switching transients. Unlike the traditional way based on the transient signal waveform, the new approach starts with the signals after relay filtering and evaluates the filtered signals according to different relay algorithms. Impact severity curves are developed for over current and impedance relays to quantify the potential risk of mal-trip due to a component switching transient. The method of quantification is not limited to component switching transients, but can be applied to any event for which sufficient waveform data is available. The impact severity curves can be used to compare two different switching transients. They can also be used in coordinating the trade-off between relay setting threshold and relay response speed.

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AUTHORS PROFILE

Sharif Shaik working as Asst. Professor, Department of Electrical & Electronics Engineering at Nimra Women's College of Engineering,, Affiliated to JNTUK, Kakinada, A.P., India. My research Interests includes Electrical Machinery, Power Electronics, and Power Systems.

N. Asha Latha working as Asst. Professor, Department of Electrical & Electronics Engineering at Nimra Women's College of Engineering,, Affiliated to JNTUK, Kakinada, A.P., India. I am pursuing second M.Tech Course in (ECE) with specialization in VLSI in Dept. of ECE. I have published papers in National and International Conferences. My research Interests includes VLSI, Power Electronics, and Digital Signal Processing.

Dawood Shaik working as Asst. Professor, Department of Electrical & Electronics Engineering at Nimra College of Engineering & Technology, Affiliated to JNTUK, Kakinada, A.P., India. My research Interests includes Power Electronics, Power Systems.