ADVANCED FRAMEWORK FOR PQ ASSESSMENT

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ABSTRACT

This paper reports new software developments for automatic power quality data analysis. The overall structure of the software is described. Functions and interactions between the four main modules, i.e., Detection and Classification of Voltage Disturbances, Voltage Sag Characterization, Fault Location, and Load Behavior Analysis, are illustrated. The module Voltage Sag Characterization is taken as an example to demonstrate some implementation issues.

INTRODUCTION

In a power system, faults, dynamic operations, or non-linear loads often cause various kinds of power quality disturbances such as voltage sags, voltage swells, switching transients, impulses, notches, flickers, harmonics, etc [1-2]. Efficient and prompt detection, and classification, characterization of the events as well as further identification of the source of these events facilitate maintenance and control of the system, and improve system stability and reliability. Usually, utilities install some power quality meters or digital fault recorders at certain locations so that these events can be recorded and stored in the form of sampled data for further analysis. Manual analysis of these data is often tedious, time consuming and even difficult. Additionally, with the exploding growth of the volume of the power quality data, it is increasingly desirable that the power quality data be analyzed automatically.

It is for this purpose that we are presently developing new software. The software aims at automatically classifying, characterizing and locating the source of various power quality events. Besides, the software performs load behavior analysis. Currently, we are studying how the load of interest is affected by the voltage sag events. Effects of various sag parameters on the load behavior are thoroughly studied and tabulated. Based on these analyses, the software can explain or predict the behavior of the loads of interest during the sag events.

OVERALL STRUCTURE OF THE SOFTWARE

The overall software consists of four application modules as depicted in figure 1. The functions, inputs and outputs of these four modules for the voltage sag application are discussed as follows.

Detection and Classification of Voltage Disturbances

This module automatically detects and classifies the types of the disturbances captured in the recorded or simulated voltage waveforms. The data flow is shown in Figure 2. The sub-module "Data Format Conversion" converts the inputs from a specific recording device or simulation package format into a common format comprehensible to other modules of the software. "Fourier and Wavelet-Transform Based Feature Extraction" extracts the distinctive features of various power quality disturbances using both Fourier and wavelet-transform based techniques. The "Fuzzy Expert System for Detection and Classification" utilizes fuzzy logic and expert system for detection and classification of the input waveforms.

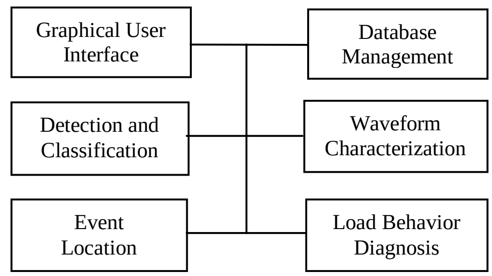

Figure 1. The overall software structure

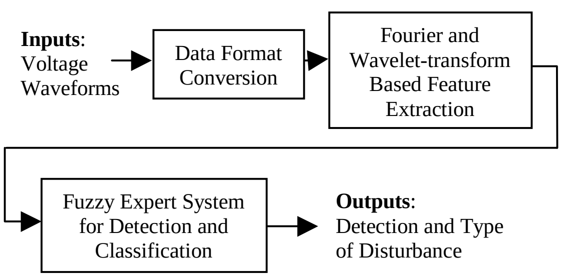

Figure 2. Detection and classification flow chart

Voltage Sag Characterization

After the recorded or simulated voltage waveforms are identified as voltage sag disturbances, this module computes various voltage sag parameters including sag magnitude, duration, phase angle jump, phase angle jump rate, voltage rms unbalance ratio, total harmonic distortion, three-phase phase angle difference, sag initial time, sag end time, and points-on wave [3]. The flow chart is shown in Figure 3.

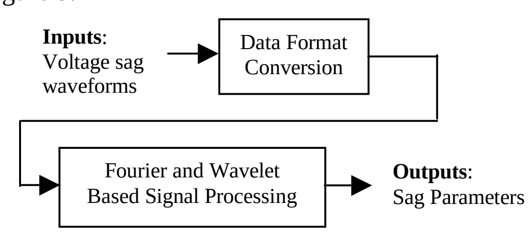

Figure 3. Sag characterization flow chart

Fault Location

Based on the waveforms recorded by a limited number of power quality meters or DFRs and the system related data, the software aims at pinpointing the location of the faults that have caused the sag captured in the recorded waveforms. Short-circuit studies are used to estimate an optimal fault location subject to a defined performance criterion. By iteratively posing faults in the system, running simulations, and comparing the simulated waveforms and the recorded waveforms, the optimal estimate of the fault location will be determined. The criterion for optimal fault location solution is stated as the one with simulated waveforms that best match the recorded waveforms.

Load Behavior Diagnosis

This module predicts or explains the behavior of the load during the sag events. Those sag parameters that led to the failure of the load during the sag events will be pinpointed. As well known, some customer loads may trip or mis-operate due to the voltage sags. With the advent of electronic devices, the trip or mis-operation may no longer be just attributed to the sag magnitude and duration. Instead, other factors like point-on-wave, unbalance ratio, and phase angle shift may also play an essential role in the behavior of the modern loads during voltage sag events. Therefore, our software aims at providing a tool for equipment sensitivity study, i.e., how various sag parameters affect the equipment behavior. Based on such studies, the software can automatically explain why a specific load failed during a sag event, and predict how well a load will perform during a particular sag event. These studies may be performed using either the recorded waveforms or waveforms generated through simulation.

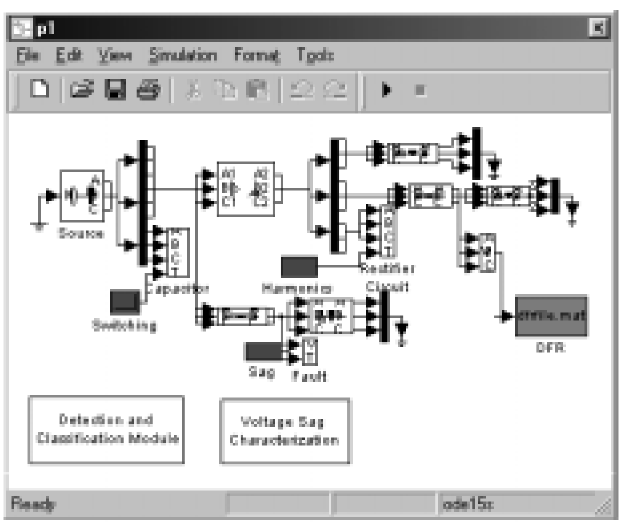

Figure 4. A sample power system.

AN EXAMPLE

A sample power system model shown in Figure 4 is used to illustrate the functions of the developed software. In the figure, the blocks ‘sag’, ‘switching’, etc. are used to generate various power quality events. The block ‘DFR’ is used to record the node voltages in a pre-specified format for later analysis. The Detection and Classification Module classifies the events, and if sag events are detected, the module Voltage Sag Characterization further categorizes them. The modules Load Behavior Diagnosis and Fault Location are still under development and not shown here. One prominent feature of this software is that the simulation and data analysis are unified in one framework. By modifying the network parameters, the corresponding changes in the recorded waveforms and the waveform parameters can be readily observed and studied. This may be essential in system planning. Table 1 shows the comparison of phase-a voltage sag parameters for sag events generated by shunt faults with different fault types or fault inception and end times. Cases 1 to 6 correspond to fault types of phase a-b-g, a-c-g, a-g, a-g, b-g, and c-g, respectively. Cases 3 and 4 are of the same fault type but have different fault end times. The differences between the parameters of these cases are clearly seen. Thus, unification of the system model and data analysis in one study environment facilitates the sag study.

Table 1. Characterization results for phase-a voltages

Case No. / Parameters	1	2	3	4	5	6
Sag Initial Time (ms)	151.1	153.5	94.99	94.99	151.8	0
Sag Initial Degree (degree)	338.4	34.82	209.0	209.0	175.2	0
Sag End Time (ms)	268.6	266.6	200.0	158.3	300.0	0
Sag End Degree (degree)	11.25	320.6	320.6	140.6	315.0	0
Initial Phase Jump (degree)	11.01	10.14	9.83	9.83	-1.03	0
End Phase Jump (degree)	-11.11	-10.74	-9.74	-10.23	1.03	0
Sag Magnitude (p.u.)	0.59	0.85	0.88	0.89	0.74	1.0
Sag Duration (ms)	117.5	113.1	105.0	63.35	148.1	0
Maximum THD	0.13	0.078	0.11	0.11	0.057	0
Maximum Unbalance Ratio	0.36	0.25	0.20	0.20	0.28	0.2

ACKNOWLEDGEMENT

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