Power Quality Disturbances Classification and Evaluation based on Power System Time Domain Characteristic Analysis

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***Abstract* — Most of the power quality disturbances classification methods are currently based on the analysis of the disturbance mathematical expressions. The analysis results cannot reflect the power system parameters and if there is any change in the power system, the results also cannot indicate the change is good or bad. This paper presents a method of power quality disturbances classification and evaluation which is based on the analysis of power systems. An IEEE 9 nodes standard model is built and all the usual single and complex power disturbances are simulated in the model. These disturbances are all classified and evaluated by the method of time domain characteristic analysis accurately. The simulation results show that this method can also be used in the power disturbance classification, and it can also reflect the systems' parameters.**

Keywords- power quality; disturbance classification; evaluation

I. INTRODUCTION

The power quality disturbance classification is the research highlights of the power quality field. So far there are many methods, such as Fourier transform[1], wavelet transform[2-4], dq transform[5], HHT transform[6-7], S transform[8-11], probabilistic neural network[12]. Fourier transform is usually used in the analysis of stationary signals[1]. Wavelet transform has an advantage of analyzing singularity and non-stationary signals[2-3]. HHT transform assimilates advantages of wavelet transform's multi resolution, and overcome the difficulties of choosing wavelet basis. S transform is the development of short time Fourier transform and wavelet transform. And it has the advantages of both. It also can analyze the signals' amplitude of every frequency component[8-11]. So it becomes hot tool of power quality classification for its analysis of a more comprehensive. A power disturbance classification method based on time domain characteristic analysis (called TDCA method in the following text) which is presented by this paper's author has been agreed by many scholars in this field. Recently there are many new methods are presented. There are three main types: time domain, frequency domain and combination of time-frequency domain. Some improves S transform[11-14], and some improves wavelet transform[15-20] or short time Fourier transform[21]. The research interests are turned to the classification of complex disturbances and disturbances location. The improved methods are better than the original methods in classifying complex disturbances, but the calculation are also more complicated. The verification method still uses the given mathematical expression of the disturbance waveform, then classifies the disturbances with other classification method and the indexes extracted.

The existing methods are mostly based on the mathematical expression of the disturbances. The main reason is that it is convenient to compare the analysis results with the known disturbance expression. And it is easier to verify the correct and accurate of the presented method. But the following problems exist with these methods:

The analysis and evaluation results of the power quality disturbance is irrelevant with the actual power system. It is only relevant with the disturbance expression. So it can't reflect the influence of the system parameter changing to the disturbance. And it can't connect the power quality disturbance analysis results with the power system, then feedback to the system, either.

So it is urgent to connect the power quality disturbance classification and evaluation results with the actual power system. Then we can deeply understand the influence of changing of the system parameters to the power quality and make some related countermeasures.

II. THE POWER QUALITY DISTURBANCE TIME DOMAIN CHARACTERISTIC ANALYSIS BASED ON SYSTEM

This paper firstly built an IEEE 9 nodes standard system as the power quality disturbance experiment system. To verify the correctness of the model, first the load flow of the system is calculated and compared with the results of FASTEST (a power system analysis software invented by State Grid Electric Power Research Institute). The results turn to be the same, then the bus 4, 5, 6, 7, 8, 9 are set three phase ground fault. The three phase ground fault voltage and generator power-angle curve are also compared with the FASTEST. The parameters of the model are adjusted until the results are all the same with FASTEST. The model is shown in Figure 1.

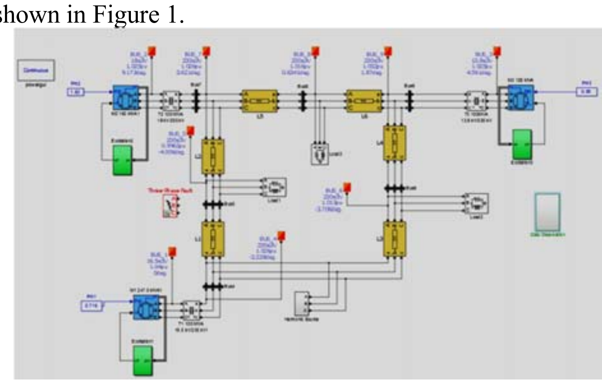

Figure 1. The IEEE 9 nodes standard Simulink model

Every disturbance simulation model is also added to the system, including harmonics, voltage sag, oscillatory transients, fluctuation and flicker, interharmonics and the complex disturbance combined by them.

A. Harmonics

To simulate the harmonic disturbance, a three phase harmonic source is added to bus 4, 5, 6, 7, 8, and 9 respectively.

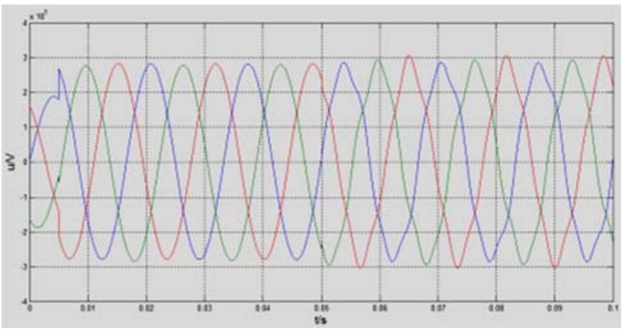

Figure 2. The voltage waveform of the bus 4

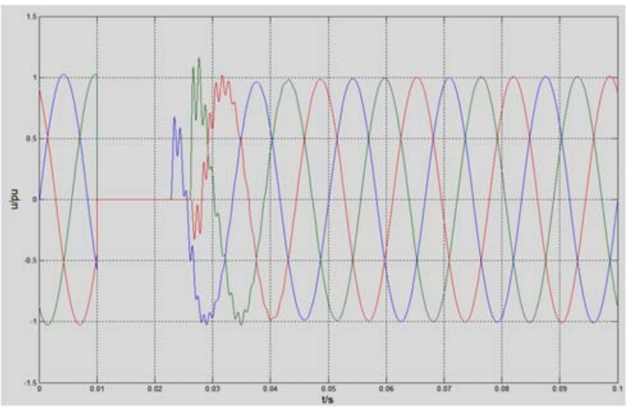

Figure 3. The bus voltage waveform of three phase ground fault

Then the voltage waveform is monitored on other buses. The TDCA method is used to classify the disturbance. The harmonic waveform on bus 4 is shown in figure 2. The harmonic source is also at bus 4. The parameters are: the fifth harmonic's amplitude is 6%, the 7th harmonic is 8%. The source is put into the system at 0.05s.

From the figure we can see that the waveform distorted clearly after 0.05s. But because of the influence of the system parameters to the harmonic spread, the THD is not the RMS of the two harmonics 10%. Instead, it is 6.63%. The results are calculated by the FFT tool in Powergui in Simulink.

B. Voltage Sag

Voltage sag is simulated by adding a three phase ground fault in all the buses. The waveforms are shown in figure 3.

The ground fault is set to begin at 0.01. We can see the short time oscillation after the short circuit. Then it gets back to the normal value.

C. Oscillatory Transients

The oscillatory transients are simulated by switching a three phase capacitor bank. The voltage waveform is shown in figure 4.

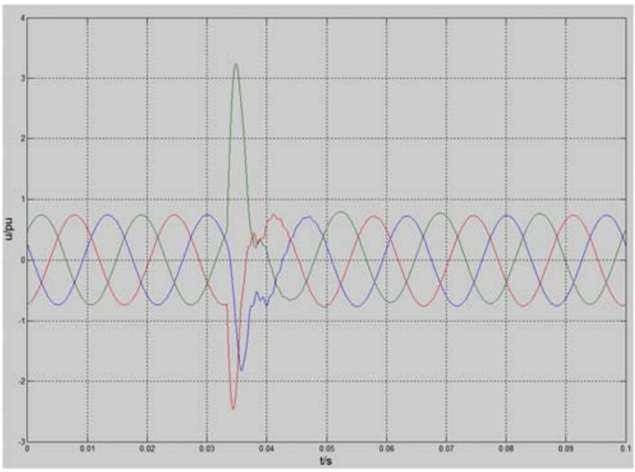

Figure 4. The bus voltage waveform of switching the three phase capacitor bank

The switching of the three phase capacitor bank simulates the oscillatory transients completely. The impulse of the oscillatory is very high which shown in figure 4. But the waveform is not generated by mathematical expression, the oscillatory process is not very long.

D. Fluctuation and Flicker

The Fluctuation and flicker is simulated by controlled source in Simulink. The disturbance source is added to one phase and the bus voltage waveform is shown in figure 5.

The controlled source is similar to an ideal source in some way. When the source is added, the voltage of that phase (the blue curve) shows the fluctuation waveform.

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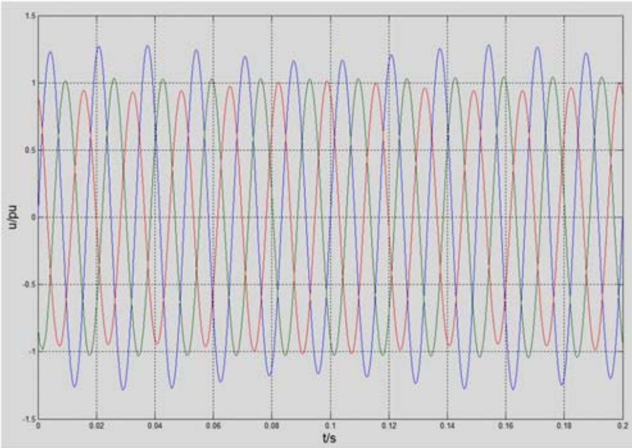

Figure 5. The bus voltage waveform of the single phase fluctuation and flicker source

E. Interharmonic

The interharmonic is also simulated by controlled source in Simulink. The frequency components are the non-integer of 60Hz. The source is also added to one phase. The bus voltage waveform is shown in figure 6.

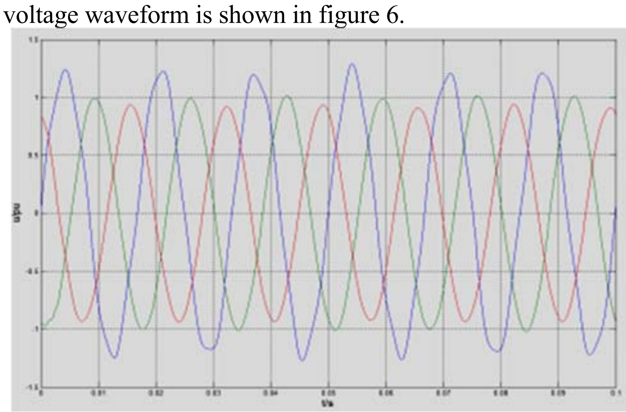

Figure 6. The bus voltage waveform of one phase interharmonic source

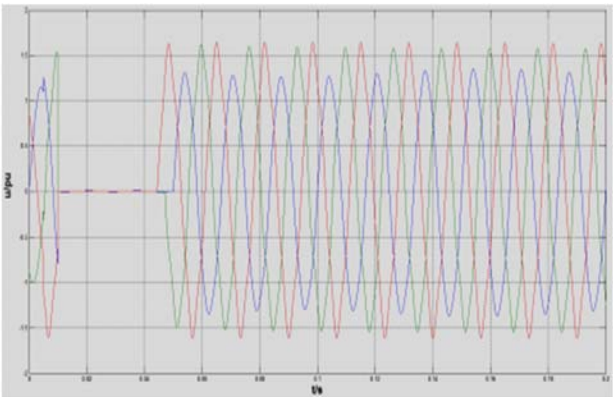

Figure 7. The bus voltage waveform of three single disturbances combined

The voltage waveform of the phase which the interharmonic source added distorts as shown in figure 6. And the distortion is different from the fluctuation which changes regularly.

F. Harmonic Plus Voltage Sag Plus Fluctuation and Flicker

The complex disturbances can be combined in many ways. This paper shows a typical complex disturbance waveform simulated in the system. Others are not shown in this chapter. Most of the simulation results are shown in the form of data in the next chapter.

Three single power quality disturbances are combined and added to the system. The bus voltage is shown in figure 7.

Three disturbances' (harmonic, voltage sag and fluctuation and flicker) characteristics all appear in the waveform of the bus which the disturbance sources are added as shown in figure 7.

III. THE CLASSIFICATION BASED ON THE TIME DOMAIN CHARACTERISTIC

According to reference [21] which is presented by this paper' author, the power quality disturbance signals can be classified as four categories by the characteristic in time domain, shown in table 1.

TABLE 1. THE CATEGORIES OF THE VOLTAGE DISTURBANCE

Voltage amplitude disturbances	Stationary	Fluctuation and flicker, under voltage ,over voltage
	Transient	Voltage sag, swell, transient interruption
Additive disturbances	Stationary	Harmonics, inter-harmonics
	Transient	Oscillatory transients, impulse voltage

Feature F_1-F_4 are extracted by the time domain characteristics and can be used to classify the single disturbance and complex disturbance [21].

This method is used to classify the disturbance which simulated above in chapter 1. The results are shown in table 2. The amplitude of the voltage sag and oscillatory transients can be measured by MATLAB function, and the THD of harmonic and interharmonic can be analyzed by FFT tool in Powergui in Simulink. The MATLAB analysis results are shown in the far right column of table 2. And the TDCA method analysis results are shown in the column next the MATLAB results.

TABLE 2. THE SIMULATION RESULTS OF SINGLE DISTURBANCE AND COMPLEX DISTURBANCE

Disturbance type	The disturbance parameters	TDCA method	MATLAB results
VS	Three phase ground fault, the amplitude is 0	0	0
FF	U_f=0.05 pu, f_f=6Hz	U_f=0.05 pu， f=6Hz	U_f=0.05 pu， f=6Hz
HA	3rd is 6%, 5th is 8%	THD=6.64%	THD=6.63%
OT	see below;	U_{max}=1.48pu	U_{max}=1.48pu
IH	f_I=152Hz, amplitude 4%	THD=4.58%	THD=4.58%
HA+VS	5th 4%, 7th 3%	THD=3.34%	THD=3.33%

HA+ FF	5^{th} 3%, 7^{th} 4%; U_f=0.05 pu, f_f=6Hz	THD=6.98%	THD=6.98%
HA+OT	5^{th} 4%, 7^{th} 3%	THD=3.35%, U_{max}=1.5pu	THD=3.35%, U_{max}=1.5pu
FF+VS	U_f=0.05 pu, f_f=6Hz	U_f=0.05 pu	U_f=0.05 pu
FF+OT	U_f=0.05 pu, f_f=6Hz	U_f=0.05 pu, U_{max}=1.5pu	U_f=0.05 pu, U_{max}=1.5pu
IH+VS	f_1=152Hz, U_1=0.02 pu	THD=4.58%	THD=4.58%
IH+OT	f_1=152Hz, U_1=0.02 pu	THD=4.58%	THD=4.58%
IH+FF	f_1=152Hz, U_1=0.02 pu ; U_f=0.05 pu, f_f=6Hz	THD=2.37% U_f=0.05 pu	THD=2.37%, U_f=0.05 pu
IH+HA	f_1=152Hz, U_1=0.02 pu ; 5th 4%, 7th 3%	THD=2.58%	THD=2.58%
IH+HA+VS	f_1=152Hz, U_1=0.02 pu ; 3th 4%, 5th 3%	THD=2.58%	THD=2.58%
IH+HA+VS+FF	U_f=0.05 pu, f_f=8Hz ; f_1=152Hz, U_1=0.02 pu ; 3th 6%，5th 8%	U_f=0.05 pu THD=3.12%	U_f=0.05 pu THD=3.12%

VS: Voltage Sag; FF: Fluctuation and Flicker; OT: Oscillatory transients; IH: Interharmonic; HA: Harmonic; OT disturbance parameters: Three phase capacitor switching; analyze the max value of the impulse U_{max}; same as follows.

U_f is the modulated wave amplitude of fluctuation and flicker, and f_f is the modulated wave frequency. U_1 is the amplitude of interharmonic and f_1 is the interharmonic frequency. The voltage sags are all classified by TDCA method, so it is not shown in table 2. The results show that TDCA method can classify all the disturbances in the system simulation, especially complex disturbances. And it can also evaluate some disturbances' parameters.

IV. CONCLUSIONS

This paper simulates the power quality disturbances based on a real power system. TDCA method is used to classify the single and complex disturbances and the results shows that it can classify them correctly. The results also compared with MATLAB analysis results and it shows that they are almost the same. When the system parameters change, the analysis will reflect the difference. That will be the research direction of the power quality disturbance classification.

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