Voltage Variation Analysis by Using Gabor Transform

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***Abstract*—Voltage variations which include voltage sag, swell and interruption are simulated and analyzed in this paper. The signals are generated by implementing parametric equation in MATLAB. Simulated signals are studies by using time-frequency distribution (TFD) technique. The TFD method used in this paper is the Gabor transform which is less applied by the researchers. The signal parameters used in this paper are the RMS voltage and instantaneous power can be extracted from the TFR to study the distinctives of the voltage variations. The parameters extracted can detect the voltage variation signals successfully. The voltage variation signals are successfully detected by using the K-Nearest Neighbors (kNN) algorithm with the implementation of signal parameters extracted as the input on the classifier. The voltage variations waveforms as well as the signal parameters obtained are suitable to be further analyzed.**

Keywords*—*MATLAB; voltage variations; power quality; time-frequency distribution; signal detection;

I. INTRODUCTION

POWER Quality (PQ) is becoming a very severe worry to users nowadays in all kinds of fields as the effects created by PQ cannot be overlooked [1]. Poor PQ can bring bad effects to the machines or production as indicated by IEEE Std. 1159-2009 [2]. The PQ problems may lead to the malfunctions or failure of the equipment and devices [3], [4]. In this research, voltage sag, swell and interruption are studied, and their parameters are being extracted.

This paper presents the voltage variation signals by using the MATLAB models studied from the previous works [5]. By implementing the modeling of voltage variation signals, the similar signal characteristics can be generated and analyzed [6]. The pattern of the models is as indicated by IEEE Std. 1159-2009 [7].

Number of methods were reviewed by research workers for analyzing PQ problems as such [8]. The main requirement in PQ study is the ability to perform data analysis. Signal processing is one of the important steps to distinguish the signals [9]–[11]. There are several famous time-frequency distributions (TFDs) techniques to analyze signal such as the Wavelet Transform, S-Transform and spectrogram [12]–[14] but not much on Gabor transform. Gabor transform determines frequency and phasor of signal with respect to time where time shifted Gaussian function in the algorithm provides higher weight on time interest.

Several methods have been proposed for classification of PQ events.[13], [15], [16]. K-Nearest Neighbors algorithm (kNN) will be implemented for the signal detection in this research. It is a non-parametric method to assign weight to the contributions of the neighbors, so that the closer neighbors attribute more to the average than the further ones [17]–[19].

In this research, Gabor-Transform technique is applied to analyse the disturbances of PQ by exhibiting the signals obtained in time-frequency representation (TFR) which consist of time and frequency format as to overcome the limitation of spectrogram in previous work [20].

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II. RESEARCH METHOD

Fig. 1 shows the flowchart of this paper. The voltage variation signals which consist of voltage sag, swell and interruption will be simulated from MATLAB and then analyzed through the Gabor transform. From the Gabor transform, the signal parameters will be extracted from the time-frequency representations (TFRs) obtained.

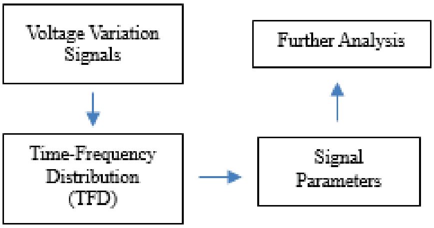

Fig. 1: Flowchart of the research

A. Voltage Variation Signals

The voltage variation signals are tough to be obtained completely. Thus, researchers are normally simulating the signals with the help of software. In this research, voltage variation signals are simulated in MATLAB R2016a with the equations as shown in Table I.

TABLE I.VOLTAGE VARIATION SIGNAL MODEL

Disturbances	Equation	Controlling Parameter
Pure Sine	a(t) = Asin(wt)	w= 2πf
Sag	a(t) =A(1 - x(u(t - t1) - u(t - t2)))sin(wt)	$0.1 \leq x \leq 0.9$; $T \leq t_2 - t_1 \leq 9T$;
Swell	a(t) =A(1 + x(u(t - t1) - u(t - t2)))sin(wt)	$0.1 \leq x \leq 0.9$; $T \leq t_2 - t_1 \leq 9T$;
Interruption	a(t) =A(1 - x(u(t - t1) - u(t - t2)))sin(wt)	$0.9 \leq x \leq 1$; $T \leq t_2 - t_1 \leq 9T$;

a(t) = PQ signal, A = Amplitude (constant), w = angular frequency, t = time,
x = time duration of event occurrence (constant), T = time duration

B. Gabor-Transform

The time and frequency resolution for Gabor transform is differ with spectrogram [20]. Gabor transform can be defined as:

$$G(t,f) = \left| \int_{-\infty}^{\infty} x(\tau) e^{\frac{-(\tau-t)^2}{2\sigma^2}} e^{-j2\pi f \tau} d\tau \right|^2 \quad (1)$$

where $x(\tau)$ is the input signal and is sigma parameter. The ordering of the matrices of Gabor transform can be presented as

$$A = \begin{vmatrix} A_{00} & A_{01} & \cdots & A_{N-4,N-1} \\ A_{10} & A_{11} & \cdots & \cdots \\ \cdots & A_{21} & A_{N-2,N-2} & \cdots \\ A_{N-1,0} & \cdots & A_{N-1,N-2} & A_{N-1,N-1} \end{vmatrix} \quad (2)$$

where A is the matrices associated with the matrix of Gabor transform time slice window. The signal is presented in MxN matrix form.

C. Voltage Variation Parameters

The parameters of voltage variation signals can be calculated from their TFRs. The parameters will be used to identify the signal characteristics [21]. In this research, the parameter of RMS voltage and power measurement will be implemented. RMS voltage can be formulated as:

$$V_{rms}(t) = \sqrt{\int_0^{f_{\max}} G_x(t,f)df} \quad (3)$$

where $G_x(t,f)$ is the TFD, f_{max} is the maximum interest frequency. The power measurement equation can be expressed as:

$$P = \frac{1}{T} \int_{t=0}^{T} v(t)i(t)dt \quad (4)$$

where $v(t)$ and $i(t)$ is voltage and current signal of the event. The total harmonic distortion is defined as the behavior of signal intensity within the non-fundamental frequency. It can be written as:

$$THD = \frac{\sqrt{\sum_{h=2}^{H} V_{h,rms}^{\;2}}}{V_{rms}} \quad (5)$$

where $V_{k,rms}$ is the RMS harmonic voltage, V_{rms} is the RMS voltage, H is the highest measured harmonic integral.

D. Signal Detection

The parameters of the voltage variation signals obtained are given as input to kNN for signal detection purpose. The kNN as mentioned above, is a non-parametric prediction algorithm where it searches the most similar feature vectors within the historical database to predict future values. The model has simple structure and high computation efficiency where best k value is selected (k=3)[22]. According to the literature, the k value must be selected carefully to fulfill the specification of the model employed. In this study, kNN in MATLAB toolbox will be used in which the weigh is utilized instead of the k value where it is formulated as:

$$weight = \frac{1}{(d_{st})^2} \quad (6)$$

where d_{st} is the distance of Euclidean. The distance of Euclidean itself in (5) can be written as:

$$d_{st} = \sqrt{(x-y)(x-y)'} \quad (7)$$

where x and y are the vectors of the model.

III. RESULTS AND DISCUSSION

The variation signals are obtained by simulated through the equation in MATLAB software. The fundamental frequency and sampling frequency of the research is 50Hz and 12kHz respectively. The TFR and Vrms graph of the MATLAB models are presented in Fig. 2 and Fig. 3. The parameters acquired from the TFDs are tabulated in Table II.

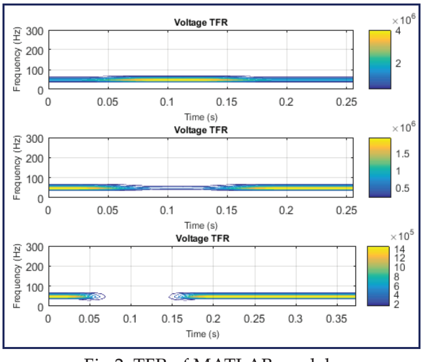

Fig.2: TFR of MATLAB models

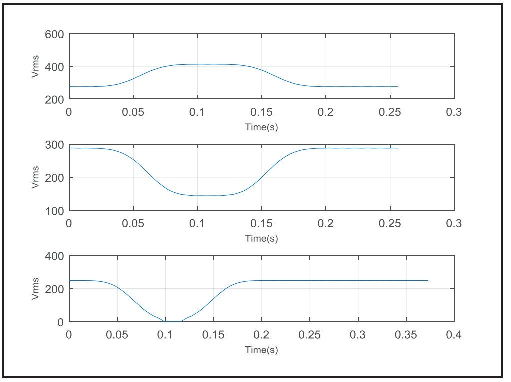

Fig.3: RMS Voltage Graphs

TABLE II. TABULATION OF PARAMETERS

Categories	Variation	Values Obtained
RMS Voltage	Sag Swell Interruption	257.99V 262.07V 231.02V
Total Harmonic Distortion (THD)	Sag Swell Interruption	19.57% 15.12% 38.98%
Instantaneous Power	Sag Swell Interruption	2596.10W 2483.13W 1894.81W

TABLE III. SIGNALS DETECTION

Variation	Number of Signals	Detection Accuracy (%)
Sag	20	100
Swell	20	!00
Interruption	20	100

Based on the TFRs and RMS graphs obtained, the signals were detected at 50Hz. The higher the power magnitude the lighter the color of the contour plot will be indicated, while the darker color indicated lower power magnitude. The voltage variation occurred from 0.05s until 0.15s (which had a period of 0.10s) with an increasing magnitude and RMS voltage differed from the initial value was voltage swell. During voltage sag, there was a sudden decrease in power magnitude from the nominal magnitude as well as RMS voltage in between

0.05s to 0.15s. during the occurrence of voltage interruption, there was a sudden halt between 0.05s to 0.15s in power magnitude where no magnitude contour was acquired.

The RMS voltage during 0.05s to 0.15s dropped to zero when voltage interruption occurred. The RMS voltage was then returned to normal after the period of voltage interruption was over. The RMS voltage, instantaneous power and THD were extracted and calculated from the TFR obtained for each case.

Table III shows the detection of the voltage variation signals. The features of signal parameters extracted from the TFR are used as the input for kNN classifier. The kNN can successfully detect the voltage variation signals.

In general, Gabor transform analysis is more computationally complex and this method enables direct energy projection in time-frequency plane. So, it is possible to evaluate the voltage variation energy and localize it in time and frequency domains accurately. Therefore, Gabor transform can be applied in postprocessing to monitor the power supply and power quality.

IV. CONCLUSION

Simulation of voltage variations has been performed with the help of MATLAB software. The signals simulated can be analyzed by using TFD technique to extract the characterized features of the signals interested. This paper shows that Gabor transform is able to analyze voltage variation signal. The features extracted can be applied for signal detection. These parameters are available for further analysis as well.

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