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Power Quality Events Detection & Classification using Gaussian Mixture Model

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Abstract—*this study introduces a Gaussian Mixture Model based modeling approach for detection and classification of Power Quality Events. This approach requires the least complex techniques for detection and classification and still provides accurate results. Time required for detection of the power quality disturbance should be small enough so that the further mitigation action may be taken. The proposed method is able to detect the disturbances in 3–5 samples. The proposed method is principally based on multivariate Gaussian mixture which has been combined so as to give the probability density function of each disturbance, the voltage sag, swell, harmonics, interruption, transient and spikes . The method detects the transient in 3–5 samples at sampling frequency of 1 kHz. Gaussian Mixture Model uses the prior knowledge of the power system disturbance to compute the unknown parameter in the form of matrix some other parameters like entropy and standard deviation is also calculated to analysis randomness due to disturbances. The parameters have been used to detect the events in the signal. Magnitude of parameters play vital role to detect the events.*

Keywords*: Power quality events, Gaussian Mixture Model (GMM), entropy weight, standard deviation.*

1. INTRODUCTION

Power quality measures the goodness of electronic devices and electric power. Correctness of the phase and frequency allows electrical systems to work properly. The term Power quality is used to explain electric power that drives an electrical load and the load's ability to function properly. There are many causes in which electric power can be of low quality. The Power industry comprises electricity generation (AC power), transmission and finally distribution to a user premises. The various level of disturbances which added due to complexity of the system to move electric energy from the point of production to the point of consumption combined with variations in demand, generation, weather and other factors provide many opportunities for the quality of supply to be low grade [1]. The importance of power quality issue is primarily due to increase in use of sensitive power electronic equipments, low balanced power system, increased use of solid state devices, lighting controls, automated and data processing equipments non linear loads and loads that are power electronically Switched, as well as industrial rectifiers and inverters [2]. Power Quality (PQ) events such as sag, swell, transients, harmonics, notch, fluctuation and flicker are the most common types of disturbances that occur in a power line. High cost equipment's connected to the power line are prone to these disturbances get affected or damaged due to disturbances that randomly occur for very short durations. Voltage dips are considered one of the most severe disturbances to the industrial equipment. Swells and over voltages can cause over heating tripping or even destruction of industrial equipment such as motor drives. Electronic equipments are very sensitive loads against harmonics because their control depends on either the peak value or the zero crossing of the supplied voltage, which are all influenced by the harmonic distortion. This research analyzes the key issues in the power quality problems. The power quality disturbance that mostly occur and most severe in industry is voltage dips. A paper machine can be affected by disturbances of 10% voltage drop lasting for 100ms. A voltage dip of 75% (of the nominal voltage) with duration shorter than 100ms can result in material loss in the range of thousands of US dollars for the semiconductors industry. Swells and over voltages can cause over heating tripping or even destruction of industrial equipment such as motor drives. Thus, it is appropriate to estimate the presence of disturbance, and classify aptly the disturbances. In the past decade various Fourier transform based technique used to analyze power quality events. Short-Time Fourier Transform (STFT) generally used for stationary and periodic signals in frequency domains. It is not easy to analyze non-stationary signal with STFT[11]. Hybrid method like wavelet- Fourier algorithm which can easily analyze transient and harmonics also used in last decade[20]. Wavelet-Transform produces feature vectors for each disturbance. One more signal processing technique called Slant Transform (ST) also used in feature extraction of power quality events. By multiplying WT with phase term, we will get ST[3]. ST is a time–frequency spectral localization Method like STFT but with Gaussian window whose width scales inversely and height linearly with the frequency. The wavelet analysis expands the signal in terms of wavelets which are generated in the form of translations and dilations of a fixed function called the mother wavelet [6]. The Wavelet Transform (WT) traces the signal changes in time domain and simultaneously decomposes the signal in frequency domain. The advantage of using WT is that it does not need to assume the stationarity and periodicity of signals. The Continuous Wavelet Transform (CWT) and Discrete Wavelet Transform (DWT) have been proposed in the literature for the detection of disturbances [4]. CWT to analyze non-stationary harmonic distortions, the applications of CWT to estimate the time duration of the disturbances. The CWT techniques proposed in literature are based on detection of disturbances in the time-scale plane [18]. The CWT based statistical approach for the analysis and detection of transient signals. However, the main disadvantage of CWT is its redundancy of using large number of scales resulting in a significant computational overhead. In order to avoid the redundancy in CWT, the DWT is proposed for disturbance detection [8]. The amplitude-frequency estimation based signal processing technique is based on representing the signal in complex form or in analytic form[10]. The analytic representation is used for finding the trajectory of the signal. The space phasor of the signal is obtained by transforming the three dimensional signal into one dimensional complex signal[5]. Hilbert Transform is used for finding the envelope of the analytic signal. The features of the disturbance waveforms are derived from its envelope. Hilbert Transform used for the analysis of flicker signal by finding its envelope. The Hilbert Transform is proposed for determining the trajectory of the signal which is used for distinguishing the disturbances. Further, features are extracted from the envelope of the signal which is obtained using the Hilbert Transform[7]. These features are less sensitive to noise and this method is found to be effective in classifying the disturbance waveforms even in the noisy environment.

This paper proposes a new event detection scheme for PQ analysis, based on a Gaussian Mixture Model algorithm for feature extraction of power quality events. This method is developed to detect and classify various single as well as multiple simultaneous PQ disturbances. In this paper, clear visual localization and detection have been investigated thoroughly for each of the power signal disturbances using GMM.

2. GAUSSIAN MIXTURE MODEL

A Gaussian Mixture Model (GMM) is a parametric probability density function represented as a weighted sum of Gaussian component densities. GMMs are commonly used as a parametric model of the probability distribution of continuous measurements or features in a Power Quality events analysis. GMM parameters are estimated from training data using the iterative Expectation-Maximization (EM) algorithm or Maximum A Posteriori (MAP) estimation from a well-trained prior model [14]. A Gaussian mixture model is a weighted sum of M component Gaussian densities as given by the equation,

$$p\left(\frac{x}{\lambda}\right) = \sum_{i=1}^{M} w_i g(x/\mu_i, \Sigma_i) \quad (1)$$

where x is a D-dimensional continuous-valued data vector (i.e. measurement or features), wi, i = 1, . . . ,M are the mixture weights, and g(x|μi,i), i = 1, . . . ,M are the component Gaussian densities. Each component density is a D-variate Gaussian function of the form with mean vector μi and covariance matrix (Σ_i). The mixture weights satisfy the constraint thatPMi=1 wi=1.The complete Gaussian mixture model is parameterized by the mean vectors, covariance matrices and mixture weights from all component densities.

Gaussian are acting together to model the overall feature density, full covariance matrices are not necessary even if the features are not statistically independent. The linear combination of diagonal covariance basis Gaussians is capable of modeling the correlations between feature vector elements. The effect of using a set of M full covariance matrix Gaussians can be equally obtained by using a larger set of diagonal covariance Gaussians. GMMs can be used in PQ, events analysis, due to their capability of representing a large class of sample distributions. One of the powerful attributes of the GMM is its ability to form smooth approximations to arbitrarily shaped densities. The classical uni-modal Gaussian model represents feature distributions by a position (mean vector) and a elliptic shape (covariance matrix) and a vector quantizer (VQ) or nearest neighbor model represents a distribution by a discrete set of characteristic templates GMM's mixture weights can be given as

$$\overline{p}_i = 1/T \sum_{t=1}^{T} p(i \mid \vec{x}_t, \lambda) \quad (2)$$

And its mean is given as

$$\vec{\mu}_i = \frac{\sum_{t=1}^{T} p(i|\vec{x}_t,\lambda)\vec{x_t}}{\sum_{t=1}^{T} p(i|\vec{x}_t,\lambda)} \quad (3)$$

3. POWER QUALITY DISTURBANCES

A **Voltage Sag** (in American) or voltage dip (in British) is a short duration reduction in rms voltage which can be caused by a short circuit, overload or starting of electric motors. Voltage sag happens when the rms voltage decreases between 10 and 90 percent of nominal voltage for one-half cycle to one minute. Some references define the duration of sag for a period of 0.5 cycles to a few seconds, and longer duration of low voltage would be called"sustained sag"[9].

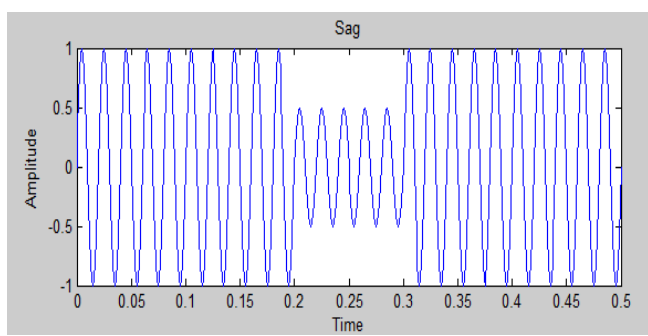

Fig. 1: Voltage sag disturbance in power quality signal.

Voltage Swell is the opposite of voltage sag. Voltage swell, which is a momentary increase in voltage, happens when a heavy load turns off in a power system[13].

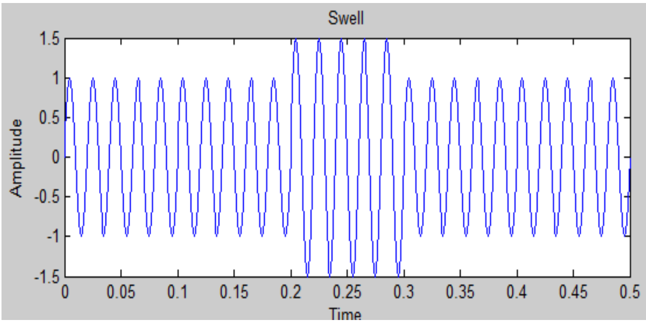

Fig. 2: Voltage swell disturbance in power quality signal.

Interruption is defined as the decrease in the voltage supply level to less than 10% of nominal for up to one minute duration. They are further subdivided into: Instantaneous (1/2 to 30 cycles), Momentary (30 cycles to 3 seconds) and Temporary (3 seconds to 1 minute). Interruptions mostly result from reclosing circuit breakers or reclosers attempting to clear non-permanent faults, first opening and then reclosing after a short time delay[12]. The devices are usually on the distribution system, but at some locations, momentary interruptions also occur for faults on the sub transmission system. The extent of interruption will depend on the reclosing capability of the protective device. For example, instantaneous reclosing will limit the interruption caused by a temporary fault to less than 30 cycles. On the other hand, time delayed reclosing of the protective device may cause a momentary or temporary interruption.

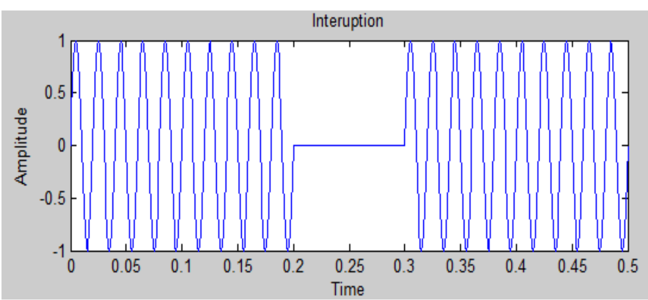

Fig. 3: Voltage interruption disturbance in power quality Signal.

Heavy loads can greatly change the load currents in an electrical distribution system. **Voltage flicker** occurs when heavy loads are periodically turned on and off in a weak distribution system. If the distribution system's short circuit capacity is not large enough, voltage fluctuations will occur. Starting large motors require an inrush of current, which causes a decrease in voltage[13]. This voltage depression may cause a visible flicker on lighting circuits connected to the same power system. Residential customers near large industrial plants often experience flickering lights. This voltage flickering can be extremely harmful to sensitive electronic equipment. Computerized equipment requires stable voltage to perform properly. For this reason, voltage flicker is a major power quality problem[15].

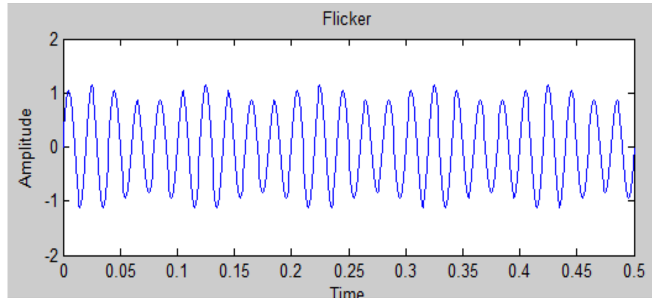

Fig. 4: Flicker disturbance in power quality signal.

Harmonic voltages and currents in an electric power system are a result of non-linear electric loads. Harmonic frequencies in the power grid are a frequent cause of power quality problems. Harmonics in power systems result in increased heating in the equipment and conductors, misfiring in variable speed drives, and torque pulsations in motors[16]. Reduction of harmonics is considered desirable.

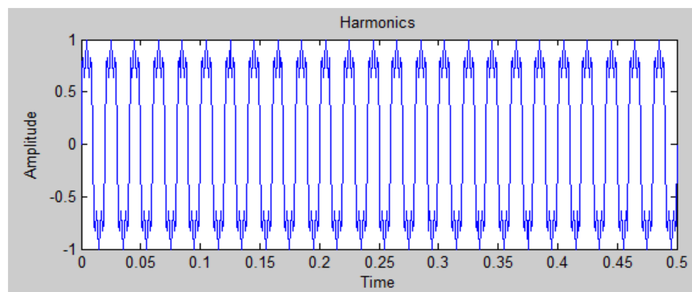

Fig. 5: Voltage Harmonics disturbance in power quality signal.

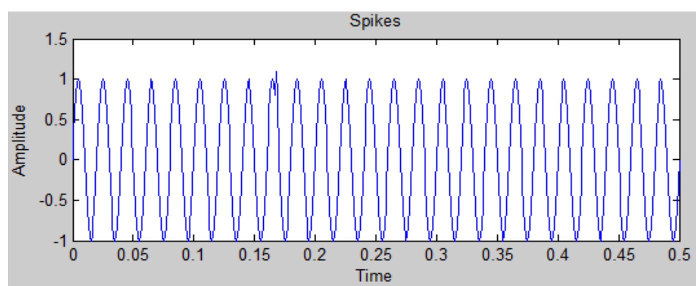

Fig. 6: Spikes disturbance in power quality signal.

Spikes are fast, short duration electrical transients in voltage (voltage spikes), current (current spikes), or transferred energy (energy spikes) in an electrical circuit. The effect of a voltage spike is to produce a corresponding increase in current (current spike). However some voltage spikes may be created by current sources. Voltage would increase as necessary so that a constant current will flow. Current from a discharging inductor is one example[17]. For sensitive electronics, excessive current can flow if this voltage spike exceeds a material's breakdown voltage, or if it causes avalanche breakdown. In semiconductor junctions, excessive electric current may destroy or severely weaken that device. An avalanche diode, transient voltage suppression diode, transil, varistor, overvoltage crowbar, or a range of other overvoltage protective devices can divert (shunt) this transient current thereby minimizing voltage.

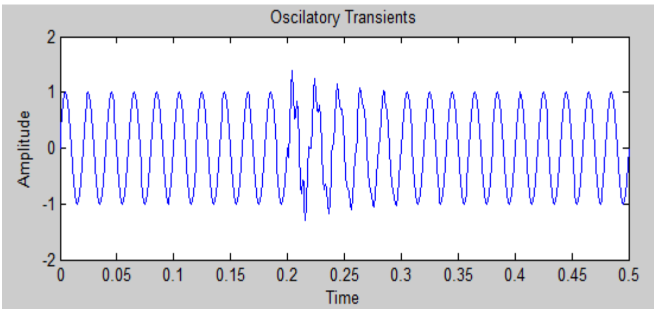

Fig. 7: Oscillatory Transients disturbance in power quality signal.

Oscillatory Transient is described as a sudden, non–power frequency change in the steady-state condition of voltage, current, or both that has both positive and negative polarity values (bidirectional). In other words, the instantaneous voltage or current value of an oscillatory transient varies its polarity quickly. It is described by its spectral content or predominant frequency, magnitude and duration. Also, oscillatory transients with fundamental frequencies less than 300 Hz can be observed on the distribution system due to transformer energization and ferroresonance[19]. In addition, series capacitors may also produce this transient type when the system resonance causes the magnification of low-frequency components in the transformer inrush current or when unusual conditions lead to ferroresonance.

Table 1: Power quality issues and their effects.

Problems	Effects
Over Voltage	Overstress insulation
Under Voltage	Excessive motor current
Unbalance	Motor heating
Neutral- ground voltage	Digital device malfunction
Interruption	Complete shut down
Sag	Variable speed drive & computer trip-out
swell	Overstress insulation
fluctuations	Light flickers

Among the various power quality problems have been identified , major concern to the customers are voltage sags and swells, but this research will cover all issues voltage sags/swells, interruption, harmonics, spikes & fluctuations. Power quality monitoring devices are widely used in power system and the study on problems of Power Quality (PQ) is made with the records of those instruments and equipments. But the data gathered by the monitoring devices is very large. So the extraction of important features from the disturbance waveforms is necessary. For extracting information from the power quality disturbances, signal processing techniques have been applied for the detection and classification of power quality disturbances.

4. RESULTS

Various events signal have been selected to apply GMM Power Quality analysis technique. These are sag, swell, harmonics, spikes, interruption, oscillatory transients, harmonics with sag and harmonics with flicker. GMM calculates Gaussian distribution function for each and every power quality events, for pure sine wave GMM distribution function comes out to be triangle. In case of sag and swell GMM distribution function comes inside and outside the triangle of pure sine wave. In case of interruption GMM distribution function is straight line.

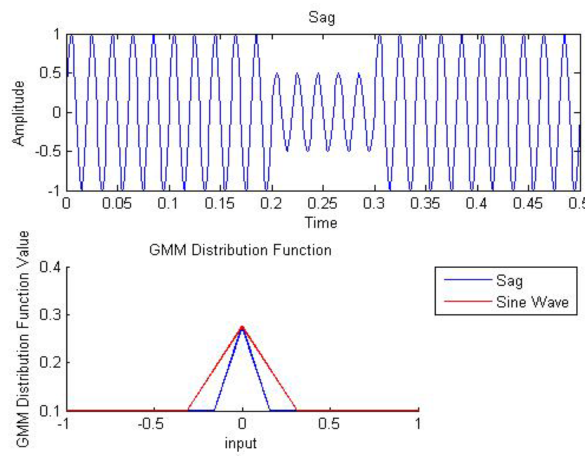

Fig. 8: GMM distributions function for sag.

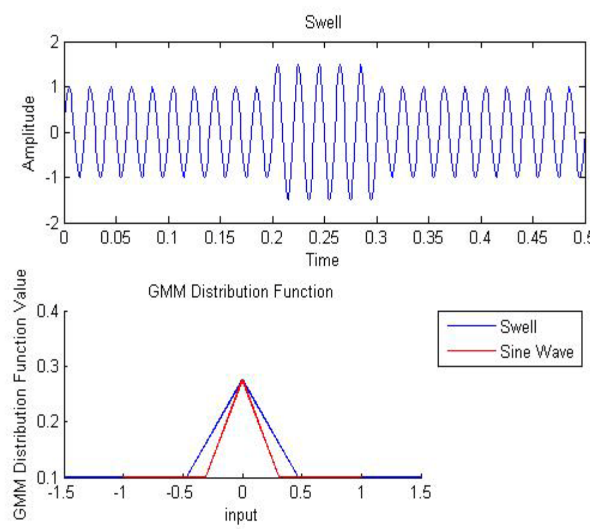

Fig. 9: GMM distributions function for swell.

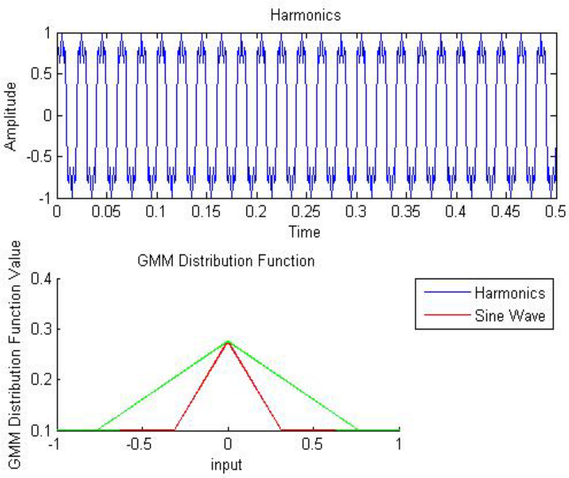

Fig. 10: GMM distributions function for Harmonics.

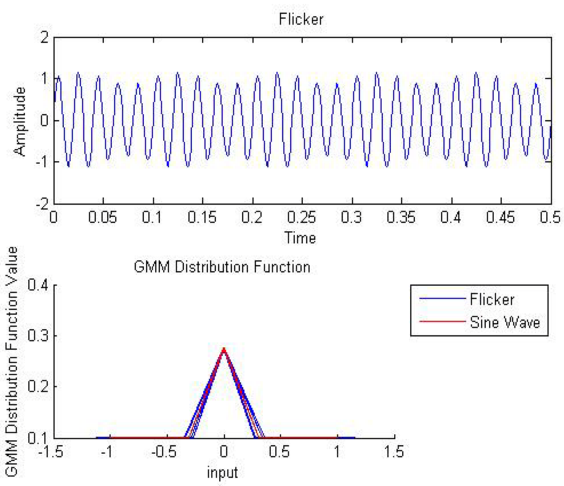

Fig. 11: GMM distributions function for Flicker.

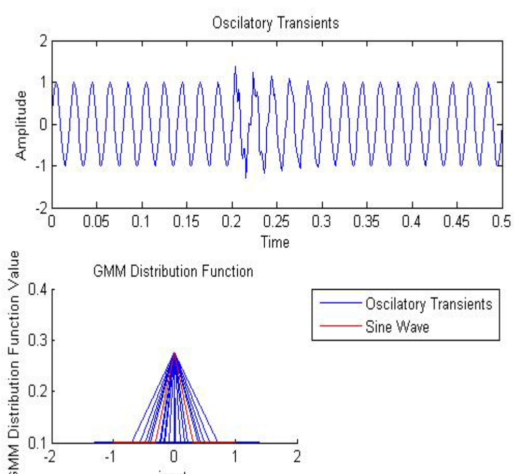

Fig. 12: GMM distribution for oscillatory transient.

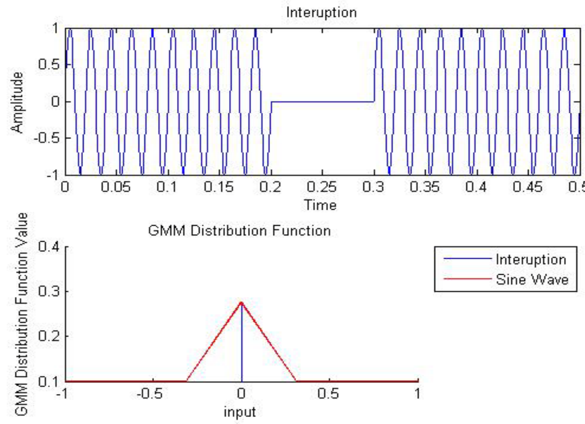

Fig. 13: GMM distributions function for Interruption.

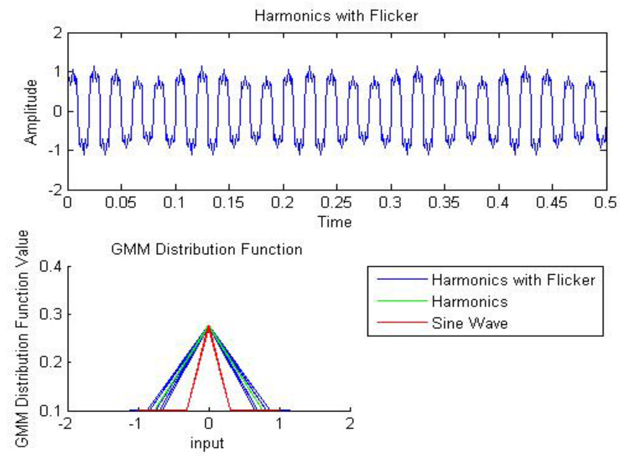

Fig. 14: GMM distributions function for Harmonics with flickers

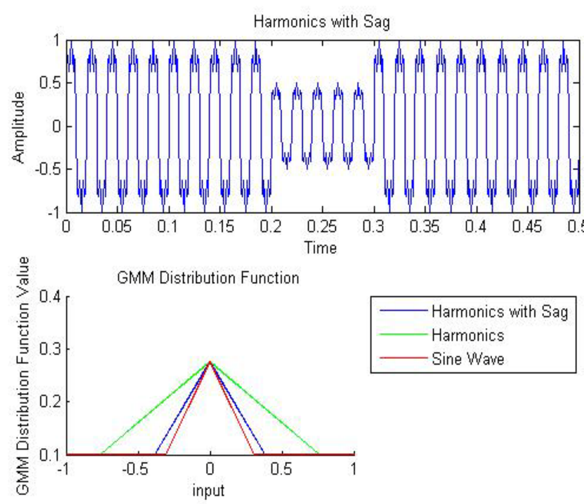

Fig. 15: GMM distributions function for Harmonics with sag.

5. CONCLUSION

In this paper, a new approach has been developed in order to identify the types of events that occur in power systems, power quality events types for each fault events are analysed in the proposed system. Superiority of this technique is simplification with reduced data set and less computation time required and various parameters like mean and GMM weights are easily calculated with the help of MATLAB tool box. This proves that performance of suggested technique is quite higher than other technique discussed in literature. The GMM is observed to be much faster and higher performance than STFT, S-T and wavelet technique, especially in terms of calculation time.

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