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IMPLEMENTATION OF INTEGRAL MATHEMATICAL MODEL OF POWER QUALITY DISTURBANCES

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Abstract: Power quality disturbances lead to severe problems in industries and electrical grids. To mitigate PQ problems, the accurate detection and classification of the possible disturbances are essential. A large number of studies exist in this field. The first research step in these studies is to obtain several distorted signals to test the classification systems. In this regard, the most common trend is the generation of signals from mathematical models. In the literature, several models with significant differences are available. However, there is no integral model that considers all types of distortions.

In this dissertation work, an integral mathematical model of power quality disturbances will be developed based on the models available in the literature. The model will include new types of combined disturbances. Almost all types of power quality disturbances will be considered under study. Further, this integral mathematical model of various power quality disturbances will be implemented for the generation of power quality disturbances using MATLAB environment. By using this model various power quality disturbances will be generated in a fast and automatic way. This model aims to facilitate future studies, supporting researchers in the modelling stage.

Index Terms - Integral Mathematical Model, Power Quality

I. Introduction:

In recent years power quality has become a significant issue for both utilities and customers. This power quality issue is primarily due to increase in use of solid-state switching devices, nonlinear and power electronically switched loads, unbalanced power system, lighting controls, computer and data processing equipment's as well as industrial plants rectifiers and inverters. PQ events such as sag, swell, transients, harmonics and flicker are the most common types of disturbances that occur in a power line. Sophisticated equipment's connected to the power line are prone to these disturbances and are affected or get damaged due to disturbances that randomly occur for very short durations. Thus, it is required to estimate the presence of disturbance, and accurately classify the disturbances and also characterize the disturbances. In order to perform the tasks such as detection, classification and characterization, it is required to understand the basic properties of PQ events and their properties. This dissertation deals with modelling of power quality disturbances for power quality analysis.

II Aim and Objectives of work

The aim of this dissertation work is to implement the Integral Mathematical Models of various Power Quality Disturbances.

Objectives:

- To study the mathematical models of various power quality disturbances.
- To implement the integral mathematical models of various power quality disturbances using the MATLAB.
- To generate single & multiple synthetic power quality disturbances as per the definition and parameters outlined by IEEE-1159 and IEC61000 customary in MATLAB using the integral mathematical models.

III. Problem Definition

Nowadays Power Quality becomes an important issue. Both utilities and customers are concern about power quality. Due to increasing use of power electronic devices various power quality disturbances are arising. This PQDs may lead to malfunctioning of end user equipment's. Hence, it is important to have a detail analysis of these disturbances and mitigate them. To study the properties and characteristics of different PQDs one may need the PQD signals. These signals can be generated by different techniques such as simulating the power quality disturbances using simulation software or generating the PQD signals by implementing the standard integral mathematical models of various PQDs using the programming software and developing the GUI for the same. The PQD signals generated by using any of the way for the analysis of PQDs called as synthetic data. One may face problem to get the data or signal for analysis, so, he can use this synthetic data readily for his research which saves his time in developing the power quality monitoring algorithms which can detect and classify various PQDs. This research work mainly focuses on generation of various PQDs by implementing their integral mathematical models.

IV. Power Quality

Power quality is simply the interaction of electrical power with electrical equipment. If electrical equipment operates correctly and reliably without being damaged or stressed, we would say that the electrical power is of good quality. On the other hand, if the electrical equipment malfunctions, is unreliable, or is damaged during normal usage, we would suspect that the power quality is poor.

Power quality is a collection of various subjects in terms of voltage quality, current quality, supply quality and consumption quality. It can be defined as: 'Any power problem manifested in voltage, current, or frequency deviations that result in failure or malfunction of customer equipment'. Poor power quality is often the main reason of unexplained equipment trips or shutdowns; occasional equipment damage or component failure; erratic control of process performance; random lockups and data errors, power system component overheating

V. Power Quality Problem

A. The power quality problem causes the deterioration of performance of various sensitive electronic and electric equipment's. The good quality of power can be specified as

• The supply voltage should be within guaranteed tolerance of declared value.
• The wave shape should be pure sine wave within allowable limits for distortion.
• The voltage should be balanced in all three phases.
• Supply should be reliable i.e continuous availability without interruption. B. Causes of poor power quality:
• Variations in voltage, magnitude and frequency
• Variations in frequency can rise of out of system dynamics or harmonics injection.

Consequently, the voltage or current waveforms of a power system ceases to be purely sinusoidal in nature but consist of harmonics and other noises.

VI. Power Quality Disturbances

• Transients are instantaneous high voltage increase in the range of nanoseconds.
• Interruption occurs when supply voltage or load current decrease to less than 0.1 pu for a period of time not exceeding 1 minute. • Voltage sag happens when the RMS voltage decreases between 10 and 90 percent of nominal voltage for one-half cycle to one minute.
• Voltage swell is the increase in the RMS voltage level to 110% - 180% of nominal voltage for a period of time not exceeding 1 minute.
• Waveform distortion is the unexpected change in the waveforms of current and voltage as they pass through a device. Table 1 shows the categorization of power quality disturbances based on time duration and voltage magnitude.

Table 1: Categorization of power quality disturbances

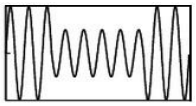
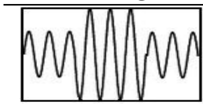
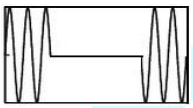
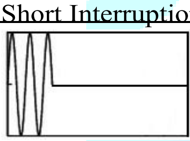
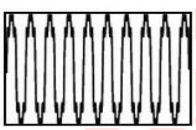
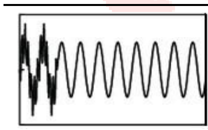
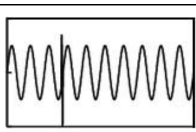
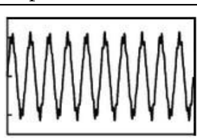
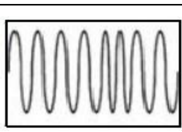
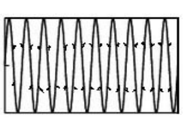
Power Quality Events		Time Duration	Voltage Magnitude
Short duration variation			
Sag	Instantaneous	0.5-30 cycle	0.1-0.9 pu
	Momentary	30 cycles-3 s.	0.1-0.9 pu
	Temporary	3 sec-1 min.	0.1-0.9 pu
Swell	Instantaneous	0.5-30 cycle	1.1-1.8 pu
	Momentary	30 cycles-3 s.	1.1-1.4 pu
	Temporary	3 sec-1 min.	1.1-1.2 pu
Interruption	Momentary	0.5 cycles-3 s.	<0.1 pu
	Temporary	3 sec-1 min.	<0.1 pu
Long duration variation			
Interruption (sustained)		>1 min.	0.0 pu
Under voltage (UV)		>1 min.	0.8-0.9 pu
Overvoltage (OV)		>1 min.	1.1-1.2 pu
Transients			
Impulsive	Nanosecond	<50 nsec.	
	Microsecond	50-1 msec.	
	Millisecond	>1 msec.	
Oscillatory	Low frequency	0.3-50 msec.	0-4 pu.
	Medium freq.	20 µsec.	0-8 pu.
	High freq.	5 µsec.	0-4 pu.
Waveform distortion			
DC offset		Steady state	0-0.1%

Harmonics	Steady state	0-20%
Inter harmonics	Steady state	0-2%
Notching	Steady state	
Noise	Steady state	0-1%
Voltage unbalance (VU)	Steady state	0.5-2%

A. Causes and Effects of Power Quality Disturbances

The power quality disturbances occurring frequently in power system. They may have adverse effect on power system equipment's. Table 2 shows the various power quality disturbances along with its causes and effects.

Table 2: Causes and effects of power quality disturbances

PQ Disturbances	Causes	Effects
 Sag	• Faults occurring in power system • Switching of large loads (ON) • Starting of large motors	• Malfunction of sensitive equipment's like PCs, PLCs, ASDs, etc. • Tripping of contactors and relays • Loss of efficiency of electric machines
 Swell	• Faults occurring in power system • Switching of large loads (OFF) • Switching of capacitor banks	• Data loss • Flickering of lighting • Failure or Damage of sensitive equipment
 Short Interruption	• Faults occurring in power system • Circuit breaker operation • Control circuit errors	• Loss of information • Malfunction of data processing equipment. • Failure of sensitive equipment, such as ASDs, PCs, PLCs.
 Long Interruption	• Failure of electrical equipment's • Storms and objects striking lines • human error • Failure of protection devices	• Failure of all equipment. • Malfunctioning in data processing devices.
 Harmonics	• Arc furnaces • Welding machines • Rectifiers • All non-linear loads • Data processing equipment • High efficiency lighting	• Resonance • Neutral overload in 3-phase systems • Overheating of all cables and equipment • Loss of efficiency in electric machines • Interference with communication systems • Nuisance tripping of thermal protections
 Oscillatory Transient	• Switching events • Electrostatic discharge • Load switching • Capacitor bank switching	• Insulation failure • Nuisance tripping of adaptable speed drives
 Impulsive Transient	• Lightning discharge • Sudden switching events	• Degradation of dielectric • Instant dielectric breakdown in equipment's
 Flicker	• Intermittent loads • Motor starting • Arc furnaces	• Flickering of lighting and screens • Damage of equipment's at load side
 Frequency Variation	• Heavy load.	• Mainly affects the motors and sensitive devices
	• Intermittent voltage distortion initiated by the power electronic devices	• Data loss • Failure or damage of sensitive devices
Notching	• Switching of heavy load	

 Transformers with bad regulation

VII. Integral Mathematical Model of Power Quality Disturbances

A. Introduction

Verification of software reference models for PQ analysis requires PQ signals; which are generated using software programs. In order to represent the real time signals accurately, mathematical equations are used to generate PQ Synthetic signals. Synthetic signals generated need to have all the properties of a real-time signal and should match the real-time signal in all aspects. Performance of PQ analysis techniques is dependent of PQ signals; hence it is required that the synthetic signals which are generated using software programs are accurately modeled. Development of software programs to generate PQ disturbances are governed by standard definitions for events as given in Table is generated.

Sag and swell events are modeled using step functions defined for periods between t1 and t2, amplitude of step function is used to control the intensity of voltages thus defining sag and swell. Time intervals t 1 and t2 define the duration of sag and swell.

Harmonic signal consists of frequency components that are multiples of 1 KHz. In a PQ signal the disturbances in terms of harmonics will have more than three frequency components and are odd multiples of fundamental component. The odd harmonics also have voltage Variations and thus affect the fundamental signal. Parameters that define amplitudes of harmonic components given by α1, α2, α3 and α4 have variations from 0.05 to 0.15 and the square sum of all components should not exceed unit magnitude. These parameters are used to

In signal disturbances that create exponential variations within a short duration of time interval are transients. Parameters such as α, w and K control the variations in transients in a given pure sine wave as shown in table 1. Transients occur for a short time interval, controlled by t1 and t2. During this time interval, the signal behaviors consist an exponential variation controlled by τ. Flicker is due to randomness in sag and swell affecting pure sine wave. Mathematical models for flicker are similar to sag and

Table 3 shows the parametric equations of power quality disturbances obtained from the integral mathematical model.

Table 3: Parametric equations of Power Quality Disturbances (PQDs)

PQDs	*Equations*	*Parameters*
Pure	$x(t) = A sin(\omega t)$	$A = 1(pu), \omega = 2\pi f\ rad/s, f = 50\ Hz$
Sag	$x(t) = A\left(1 - \alpha\left(u(t - t1) - u(t - t2)\right)\right) sin(\omega t)$	$0.1 \leq \alpha \leq 0.8, T \leq (t2 - t1) \leq 9T$
Swell	$x(t) = A\left(1 + \alpha\left(u(t - t1) - u(t - t2)\right)\right) sin(\omega t)$	$0.1 \leq \alpha \leq 0.8, T \leq (t2 - t1) \leq 9T$
Interruption	$x(t) = A\left(1 - \alpha\left(u(t - t1) - u(t - t2)\right)\right) sin(\omega t)$	$0.9 \leq \alpha \leq 1, T \leq (t2 - t1) \leq 9T$
Harmonics	$x(t) = \alpha_1 sin(\omega t) + \alpha_3 sin(3\omega t) + \alpha_5 sin(5\omega t) + \alpha_7 sin(7\omega t)$	$0.05 \leq \alpha_3, \alpha_5, \alpha_7 \leq 0.15, \alpha_1 = 1$
Flicker	$x(t) = (1 + \lambda\ sin\ (\kappa\omega t))\ sin\ (\omega t)$	$0.1 \leq \lambda \leq 0.2, 5 \leq \kappa \leq 10$
Notch	$x(t) = sin(\omega t) - sign(sin(\omega t)) \sum^{9}(K \times [u\{t - (t1 - 0.02n)\} - u\{t - (t2 - 0.02n)\}])$	$0.1 \leq K \leq 0.4, 0 \leq t1, t2 \leq 0.5T, 0.01T \leq t2 - t1 \leq 0.05T$

control the harmonic variation in a pure sine wave signal.

swell, but the duration of sag and swell is randomly added to the pure sine wave signal.

B. Integral Mathematical Model of PQDs

By varying the parameters from the equation, the duration of event and magnitude can be varied.

	( ) = ( ) + (( )) $\sum_{n=0}(K \times [u\{t-(t1-0.02n)\}-u\{t-(t2-0.02n)\}])$	0.1 ≤ ≤ 0.4, 0 ≤ 1, 2 ≤ 0.5 , $0.01T \leq t2-t1 \leq 0.05T$	Spike
Oscillatory Transient	$x(t) = sin(\omega t) + \alpha_t \exp(-\frac{t-t1}{\tau})(u(t-t1) - u(t-t2))sin(2\pi f_n t)$	$0.1 \leq \alpha_t \leq 0.8, 0.5T \leq (t2-t1) \leq 3T$ $8ms \leq \tau \leq 30ms, 300 \leq f_n \leq 900\ Hz$	
Impulsive Transient	$x(t) = sin(\omega t) + \alpha_t \exp(-\frac{t-t1}{\tau})(u(t-t1)-u(t-t2))$	$3 \leq \alpha_t \leq 4, 0.5T \leq (t2-t1) \leq 3T$ $8ms \leq \tau \leq 30ms$	
Sag with Harmonics	$x(t) = [A(1-\alpha(u(t-t1)-u(t-t2)))sin(\omega t)]x[\alpha_1 sin(\omega t) +$ sin ωt sin ωt sin ωt) + (5) + (7)]	$0.1 \leq \alpha \leq 0.8, T \leq (t2-t1) \leq 9T$ $0.05 \leq \alpha_3, \alpha_5, \alpha_7 \leq 0.15, \alpha_1 = 1$	(3
Swell with	$x(t) =$	$0.1 \leq \alpha \leq 0.8, T \leq (t2-t1) \leq 9T$	

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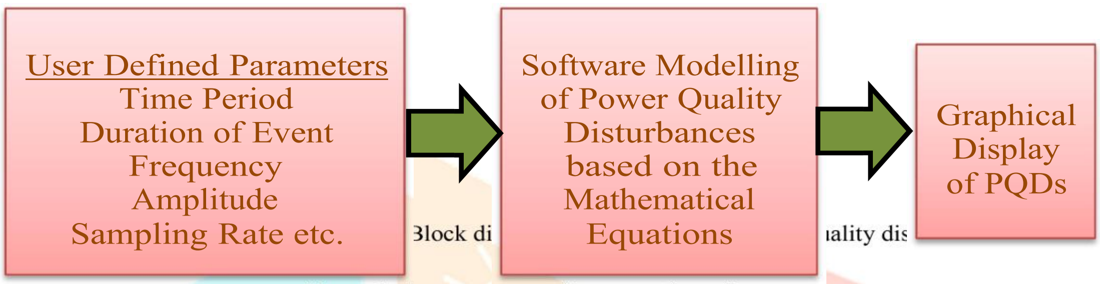
Harmonics	$[A\left(1+\alpha\left(u(t-t1)-u(t-t2)\right)\right)sin(\omega t)]x[\alpha_1 sin(\omega t)+\alpha_3 sin(3\omega t)+\alpha_5 sin(5\omega t)+\alpha_7 sin(7\omega t)]$	$0.05 \leq \alpha_3, \alpha_5, \alpha_7 \leq 0.15, \alpha_1 = 1$
Interruption with Harmonics	$x(t) = [A\left(1+\alpha\left(u(t-t1)-u(t-t2)\right)\right)sin(\omega t)]x[\alpha_1 sin(\omega t)+\alpha_3 sin(3\omega t)+\alpha_5 sin(5\omega t)+\alpha_7 sin(7\omega t)]$	$0.9 \leq \alpha \leq 1, T \leq (t2-t1) \leq 9T$ $0.05 \leq \alpha_3, \alpha_5, \alpha_7 \leq 0.15, \alpha_1 = 1$

VIII. System design

A. Block Diagram

Based on the discussions and numerical equations presented the software programs are developed for modeling power quality disturbances. Control parameters for variations in distortions or events are defined as user inputs. The known disturbances are introduced in the signal; graphical display helps in verifying the PQ events. Fig. 1 shows the block diagram for generation of power quality disturbances.



B. Flow Chart for Generation of Power Quality Disturbances

The steps involved in the software program developed for the generation of power quality disturbances are represented in the form of flow chart shown in fig. 2

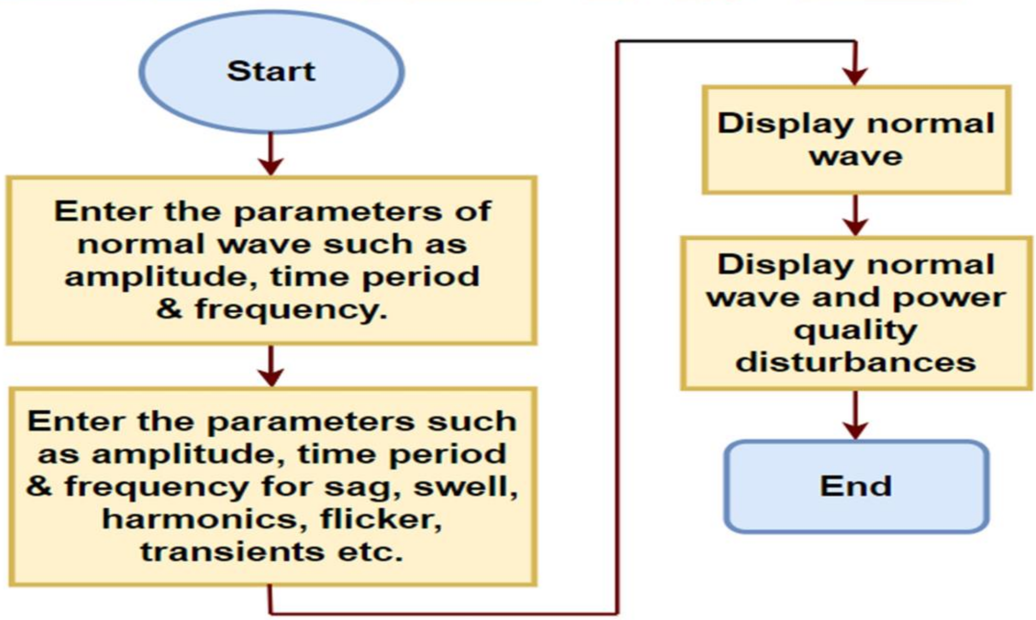


Figure.2: Flow Chart for generation of power quality disturbances.

IX. Generation of Power Quality Disturbances using MATLAB

In this dissertation the implementation of integral mathematical models of eleven power quality disturbances in the form of parametric equation is done using the software program develop in MATLAB software. Total eleven power quality disturbances are generated namely voltage sag, voltage swell, voltage interruption, harmonics, impulsive transient, oscillatory transient, voltage flicker, voltage notch, noise, voltage sag with harmonics and voltage swell with harmonics. Figure.3 shows the pure 50Hz sine wave of amplitude 1pu and time duration 0.4sec generated using the parametric equation.

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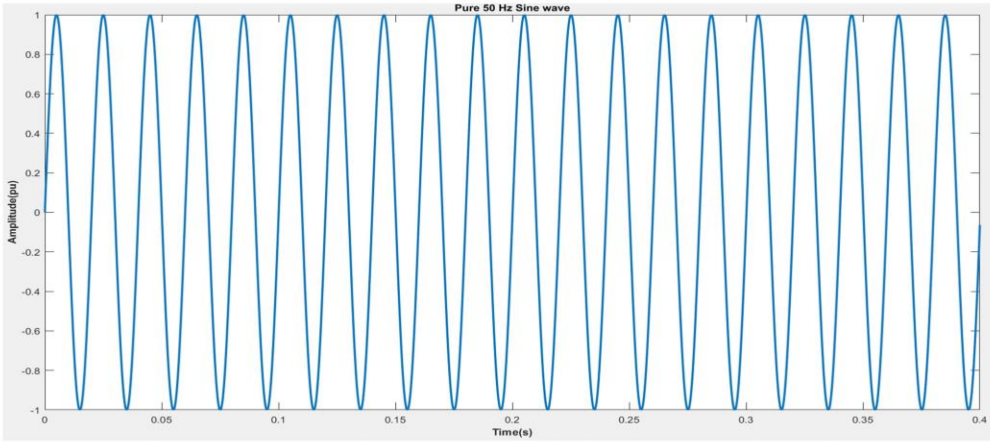

Figure.3 : Pure 50Hz sine wave generated using the parametric equation.

Figure 4 shows the voltage signal with a sag of 50% for time duration 0.2sec generated by controlling the parameters of the parametric equation.

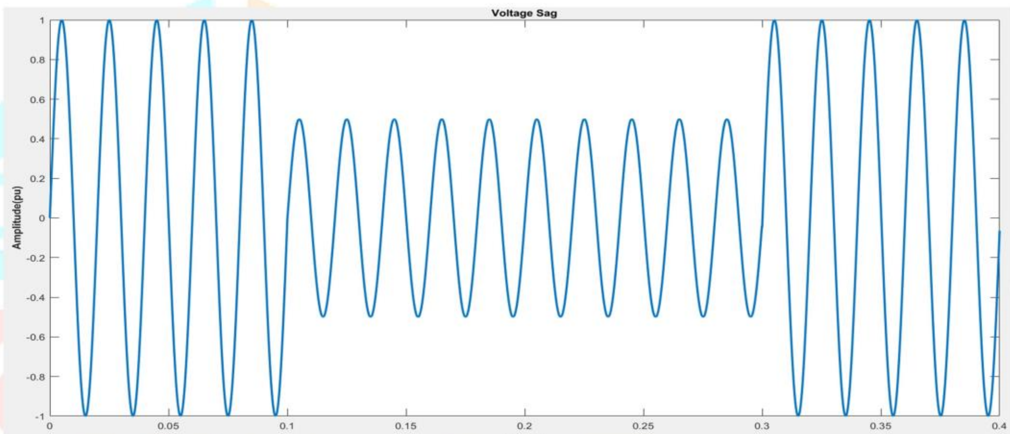

Figure 4: Voltage Sag waveform generated using the parametric equation.

Figure.5 shows the voltage signal with a swell of 150% for time duration 0.2sec generated by controlling the parameters of the parametric equation.

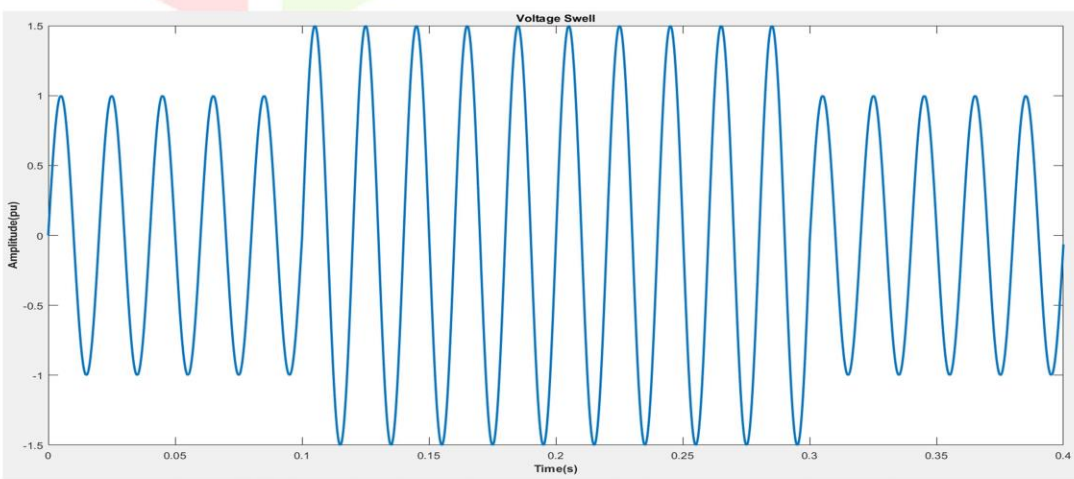

Figure 5: Voltage Swell waveform generated using the parametric equation.

Figure 6 shows the voltage signal with interruption for time duration 0.2sec generated by controlling the parameters of the parametric equation.

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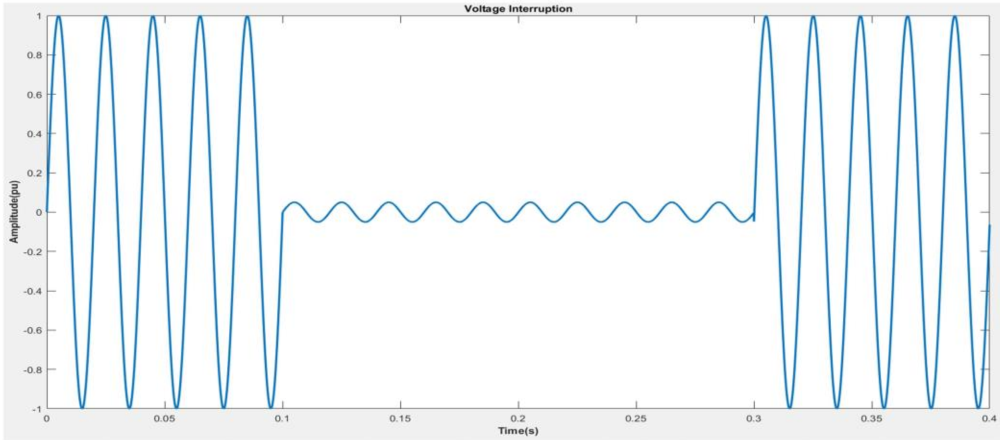

Figure 6 : Voltage Interruption waveform generated using the parametric equation.

Figure 7 shows the voltage signal with odd harmonics for time duration 0.4sec generated by controlling the parameters of the parametric equation.

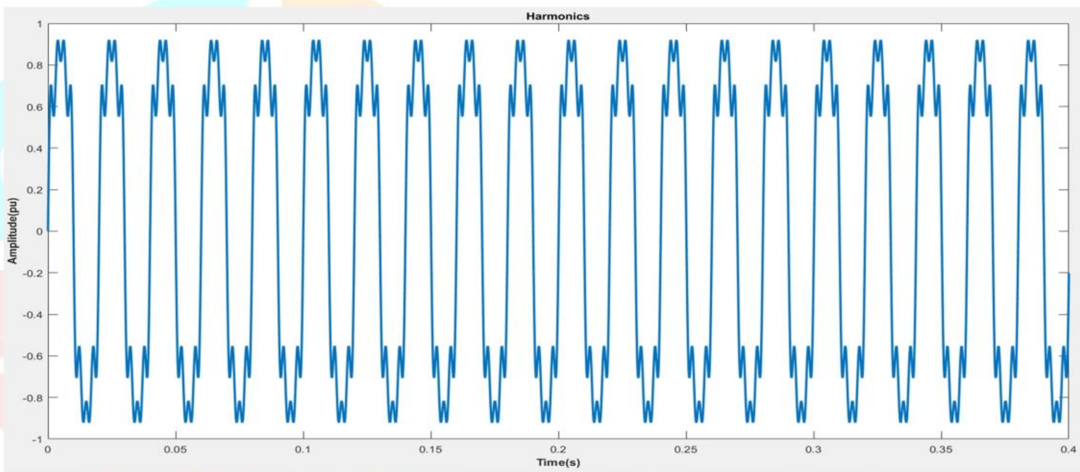

Figure 7: Harmonics waveform generated using the parametric equation.

Figure 8 shows the voltage signal with impulsive transient with positive peak of 1.4pu and negative peak of 2pu for time duration in msec generated by controlling the parameters of the parametric equation.

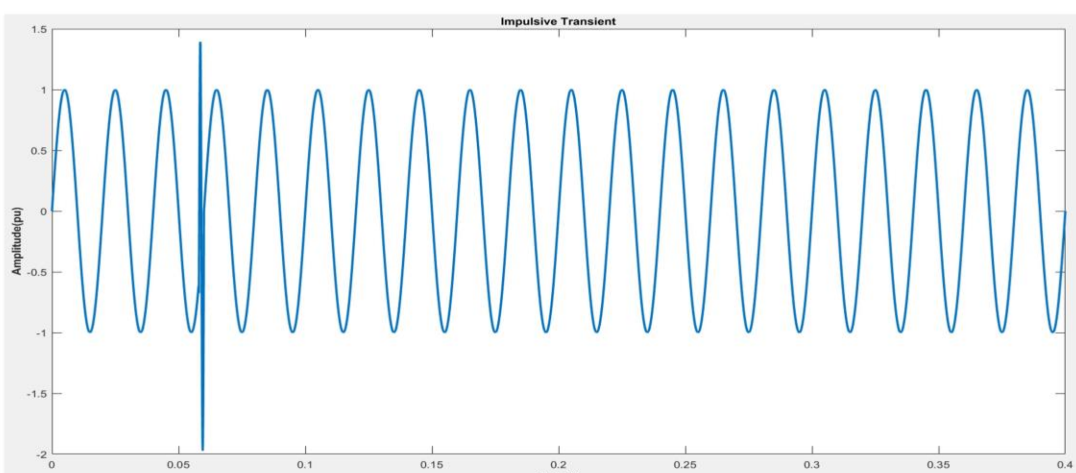

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Figure 8 : Impulsive Transient waveform generated using the parametric equation.

Figure 9 shows the voltage signal with oscillatory transients of frequency 300 to 900Hz and time duration 0.06sec generated by controlling the parameters of the parametric equation.

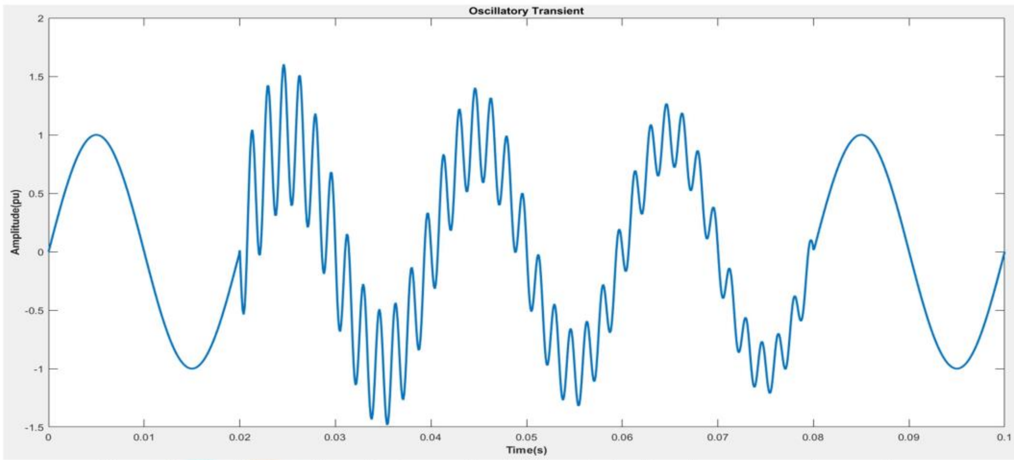

Figure 9: Oscillatory Transient waveform generated using the parametric equation.

Figure 10 shows the voltage signal with flicker for time duration 0.4sec generated by controlling the parameters of the parametric equation.

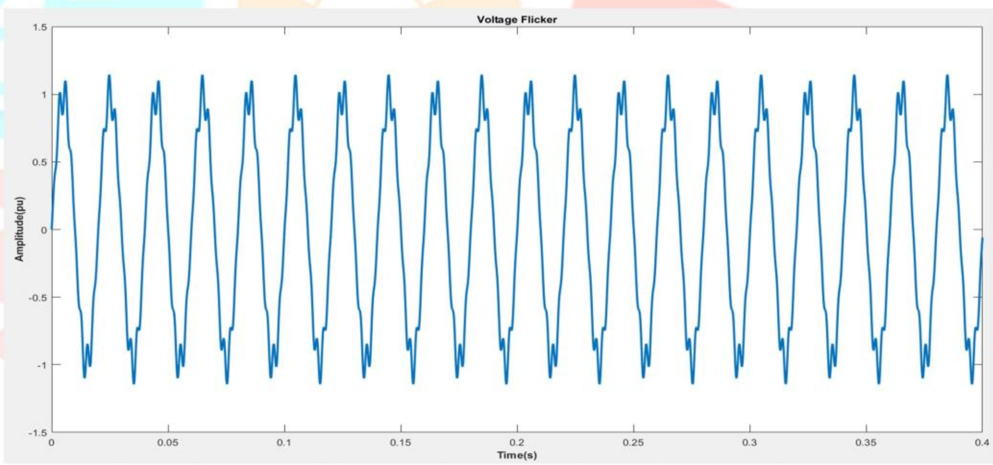

Figure 10: Voltage Flicker waveform generated using the parametric equation.

Figure 11. shows the voltage signal with notches for time duration 0.4sec generated by controlling the parameters of the parametric equation.

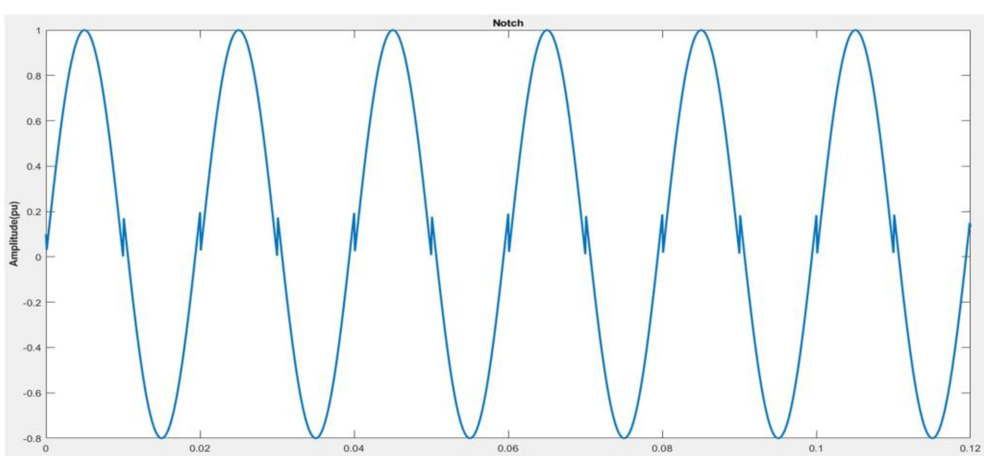

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Figure 11: Voltage Notch waveform generated using the parametric equation.

Figure 12 shows the voltage signal with noise of high SNR for time duration 0.4sec generated by controlling the parameters of the parametric equation.

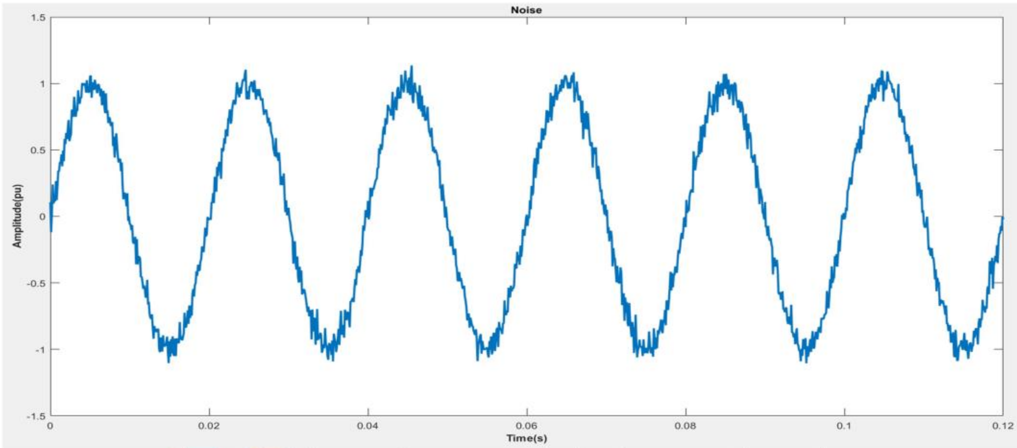

Figure 12: Noise waveform generated using the parametric equation.

Figure 13 shows the voltage signal with sag of 50% along with harmonics for time duration 0.4sec generated by controlling the parameters of the parametric equation.

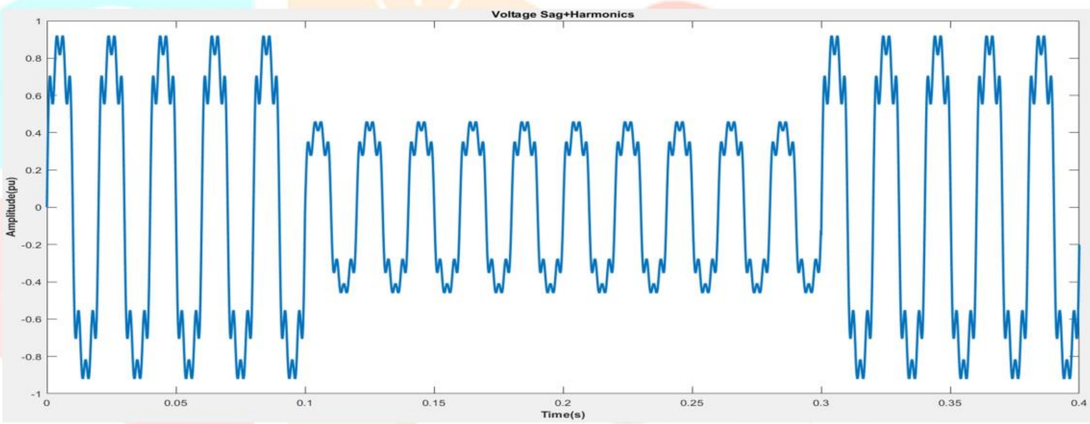

Fig 13: Voltage Sag + Harmonics waveform generated using the parametric equation.

Figure 14 shows the voltage signal with swell of 150% along with harmonics for time duration 0.4sec generated by controlling the parameters of the parametric equation.

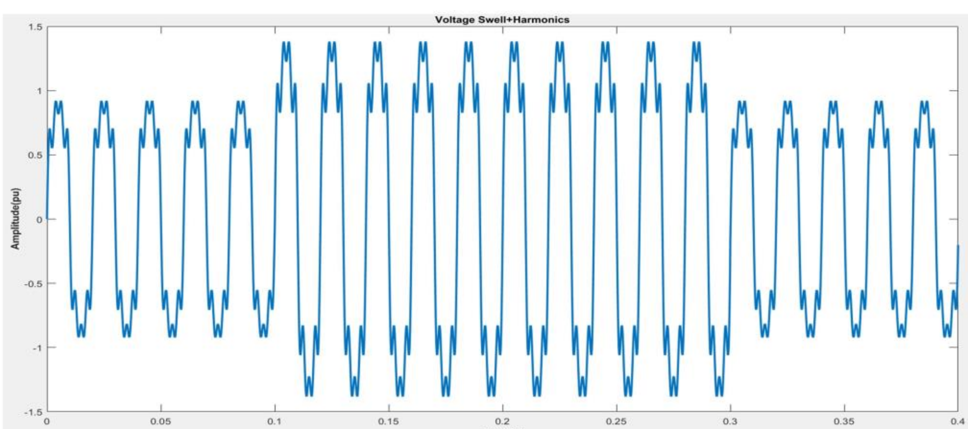

Figure 14: Voltage Swell + Harmonics waveform generated using the parametric equation.

X. Conclusion

In this dissertation an integral mathematical model comprising different types of power quality disturbances is presented.The implementation of integral mathematical model is done in the form of parametric equation using the software program developed in MATLAB. Both single & multiple synthetic power quality disturbances are generated as per the definition and parameters outlined by IEEE-1159 and IEC61000 customary in MATLAB using the integral mathematical models. This integral mathematical model proposed in this dissertation may be useful in the field of automatic detection and classification of power quality disturbances. Researchers in this field can use it to generate training and validation datasets in order to test their detection and classification algorithms. This allows checking the feasibility of their proposals rapidly, which represents an important advantage. This is especially interesting in the early stages of a research, given the reduction in the time spent that can be obtained

References.

[1] R. Igual, C. Medrano, F. J. Arcega and G. Mantescu, "Integral mathematical model of power quality disturbances," 2018 18th International Conference on Harmonics and Quality of Power (ICHQP), Ljubljana, 2018, pp. 1-6, doi: 10.1109/ICHQP.2018.8378902.

[2] Likhitha R., A. Manjunath and E. Prathibha, “Development of Mathematical Models for Various PQ Signals and Its Validation for Power Quality Analysis,” International Journal of Engineering Research and Development ISSN: 2278-067X, Volume 1, Issue 3 (June 2012), PP.37-44.

[3] M. Mishra, “Power quality disturbance detection and classification using signal processing and soft computing techniques: A comprehensive review,” International Transactions on Electrical Energy Systems, Volume29, Issue8, August 2019.

[4] Dash, S. and UmamaniSubudhi. “Multiple Power Quality Event Detection and Classification using Modified S Transform and WOA tuned SVM Classifier.” arXiv: Signal Processing (2019).

[5] Alqam, Salah &Zaro, Fouad, “Power Quality Detection and Classification Using S-Transform and Rule-Based Decision Tree,” International Journal of Electrical and Electronic Engineering & Telecommunications, 8. 10.18178/ijeetc.8.1.45-50 (2019). [6] V. Janahiraman, Tiagrajah&Bala, Prakash, “An Ensemble Classifier based Power Quality Disturbances Classification,” 9.4161-4167. 10.35940/ijeat.B4924.129219 (2019).

[7] AnkitaDandwate& K. B. Khanchandani, “Generation of Mathematical Models for various PQ Signals using MATLAB,” International Conference On Industrial Automation And Computing (ICIAC- 12-13 April 2014).

[8] R. Hooshmand, A. Enshaee, “Detection and classification of single and combined power quality disturbances using fuzzy systems oriented by particle swarm optimization algorithm,” Electric Power Systems Research, Volume 80, Issue 12, 2010, Pages 1552-1561, ISSN 0378-7796.

[9] Shaik, Aslam& A, Srinivasula, “A Novel Feature Selection Method for the Detection and Classification,” International Journal of Simulation: Systems, Science & Technology. 20. 2. 10.5013/IJSSST.a.20.01.33 (2019).

[10] Manish kumarsaini&rajivkapoor “classification of power quality events – A review “ Electrical power and energy system 43 (2012).

11] Laxmipriyasamal, Hemanta Palo &BadrinarayanSahu “ classification of power quality disturbance using wavelet packet information entropy feature vectors and probabilistic neural network” International journal on electrical engineering and informatics – volume 13 December 2021.

[12]Utkarshsingh “A research review on detection and classification of power quality disturbances caused by integration of renewable energy sources.” International journal September 2020.