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Implementation of Integral Mathematical Models of Single and Multiple Power Quality Disturbances

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Abstract: Nowadays, renewable energy resources based generation is increasingly used to feed the ever-increasing power demand. The integration of this generation with the grid requires power electronic converters. These power electronic converters, switching operations, non-linear loads, and faults occurring in the network are the major causes of Power Quality Disturbances (PQDs). These PQDs cause severe problems to the sensitive equipment of end-user. Hence, Power Quality (PQ) becomes the main issue, both utility and customers are now concern about it. To mitigate the PQ problem, we need an accurate PQ monitoring system that can detect and classify the PQDs. A lot of research is going in this field. The first step of this research is to get some synthetic data to train and test the detection and classification algorithms. So, the current trend is to generate the single and multiple PQDs using integral mathematical models represented as parametric equations. This paper presents the implementation of integral mathematical models of both single and multiple PQDs such as voltage sag, voltage swell, voltage interruption, harmonics, voltage flicker, voltage notch, impulsive transient, oscillatory transient, voltage sag with harmonics, voltage swell with harmonics, and voltage interruption with harmonics using MATLAB programming. This will provide a fast and automatic way for the generation of PQDs to the researcher working in this area.

Keywords: Power Quality; Power Quality Disturbances, Power Quality Monitoring, Detection and Classification.

I. INTRODUCTION

In the present era of science and technology, the term power quality has gained more importance. Both utilities and customers are now concerned about power quality. The power quality issues are occurring mainly due to the increasing use of non-linear loads, power electronic load/converters, solid-state devices, unbalanced loads, computer systems, and data processing units [1]. The use of renewable energy resources-based distributed generation systems with power electronic converters are also acting as a major source of power quality disturbances [2]. Power quality disturbances such as voltage sag, voltage swell, interruption, harmonics, transients, and flicker are the most commonly occurring disturbances in power systems [3]. Modern types of equipment that are connected to the system may get affected or damaged due to the exposure to the power quality disturbances occurring in the power system due to any cause [5]. Hence, it is necessary to accurately detect the occurrence of power quality disturbance, and classify it. In order to execute the task of detection, classification, and characterization of power quality disturbances, it is essential to understand its properties and characteristics. This paper deals with the generation of eleven power quality disturbances using mathematical models for power quality analysis.

II. POWER QUALITY

There are several definitions of power quality. Different international standard organization define the term power quality in different way. According to IEEE, it is defined as the concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment and compatible with the supply system and other connected equipment. According to IEC, it is defined as the ability of a device, equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

The power quality disturbances may cause malfunctioning of customer equipment. It may lead to the interruption of the manufacturing process which will damage the product and hamper the manufacturing results into loss of money. For

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proper functioning of the electric and electronic equipment's the supply quality must be good. The properties of good power quality are

- The supply voltage should be rated or within the tolerance limit.
- The three-phase voltage should be balance.
- The supply frequency should be rated or within the tolerance limit.
- The nature of the alternating wave should be purely sinusoidal within the allowable distortion limits.

The most common types of power quality disturbances are discussed below

- **Voltage sag** is the reduction in the RMS value of the voltage between 10% to 90% of nominal voltage for a period less than one minute.
- **Voltage swell** occurs when the RMS value of voltage increases to 110% - 180% of nominal voltage for a period not exceeding one minute.
- **Interruption** is the decrease in the value of supply voltage below 0.1 pu for a period less than one minute.
- **Harmonics** is the signal in which the frequency of a signal is multiple of the fundamental frequency.
- **Transients** are the instantaneous rise in the voltage value for a very short duration.
- **Waveform distortion** is the unpredicted change in the value of current and voltage waveforms when they are applied to any device.

Table 1 shows the categorization of power quality disturbances in different groups along with the time duration and variation in voltage magnitude.

Table I 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
Undervoltage (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%
Interharmonics		Steady state	0-2%
Notching		Steady state	
Noise		Steady state	0-1%
Voltage unbalance (VU)		Steady state	0.5-2%

III. INTEGRAL MATHEMATICAL MODELS OF POWER QUALITY DISTURBANCES

The integral mathematical models of PQDs are represented by a set of parametric equations using different mathematical functions in order to generate the required power quality disturbance. The magnitude and duration of the disturbances are controlled by controlling the parameters of parametric equations. These mathematical models are used to generate the synthetic power quality signals. This will help to represent the real-time power quality signals accurately. The

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generated synthetic power quality signals will have the same characteristics as the real-time power quality signals have in all standpoints [2]. The performance of the power quality disturbance detection and classification algorithm is dependent on PQ signals. Hence, it is necessary to accurately model and implement the software program for the generation of synthetic power quality signals.

In the integral mathematical models of PQDs, the representation of voltage sag, voltage swell, and interruption events is done using the step function. The amplitudes of these events are controlled by the parameter A and the duration is controlled by t1 and t2 [2]. Harmonic event is represented by the algebraic sum of sine functions of different frequencies and the parameters α1, α2, α3, and α4 are varied from 0.05 to 0.15 in order to control the harmonic [9]. The transients are represented by the exponential function where the parameters α, w, and K controls the transients in a sinusoidal wave. Flicker is represented by randomizing the sine wave.
Table 2 shows the parametric equations of power quality disturbances obtained from the integral mathematical model. By varying the parameters of the equation, the duration of the event and magnitude can be varied.

Table II 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
Voltage Sag	$x(t) = A\left(1 - \alpha\left(u(t - t1) - u(t - t2)\right)\right)\sin(\omega t)$	$0.1 \le \alpha \le 0.8, T \le (t2 - t1) \le 9T$
Voltage Swell	$x(t) = A\left(1 + \alpha\left(u(t - t1) - u(t - t2)\right)\right)\sin(\omega t)$	$0.1 \le \alpha \le 0.8, T \le (t2 - t1) \le 9T$
Interruption	$x(t) = A\left(1 - \alpha\left(u(t - t1) - u(t - t2)\right)\right)\sin(\omega t)$	$0.9 \le \alpha \le 1, T \le (t2 - t1) \le 9T$
Harmonics	$x(t) = \alpha_1\sin(\omega t) + \alpha_3\sin(3\omega t) + \alpha_5\sin(5\omega t) + \alpha_7\sin(7\omega t)$	$0.05 \le \alpha_3, \alpha_5, \alpha_7 \le 0.15, \alpha_1 = 1$
Voltage Flicker	$x(t) = (1 + \lambda\sin(\kappa\omega t))\sin(\omega t)$	$0.1 \le \lambda \le 0.2, 5 \le \kappa \le 10$
Voltage Notch	$x(t) = \sin(\omega t) - \mathrm{sign}(\sin(\omega t))\sum_{n=0}^{9}(K \times [u\{t - (t1 - 0.02n)\} - u\{t - (t2 - 0.02n)\}])$	$0.1 \le K \le 0.4, 0 \le t1, t2 \le 0.5T,$ $0.01T \le t2 - t1 \le 0.05T$
Oscillatory Transient	$x(t) = \sin(\omega t) + \alpha_t\exp\left(-\frac{t-t1}{\tau}\right)\left(u(t - t1) - u(t - t2)\right)\sin(2\pi f_n t)$	$0.1 \le \alpha_t \le 0.8, 0.5T \le (t2 - t1) \le 3T$ $8ms \le \tau \le 30ms, 300 \le f_n \le 900$ Hz
Impulsive Transient	$x(t) = \sin(\omega t) + \alpha_t\exp\left(-\frac{t-t1}{\tau}\right)\left(u(t - t1) - u(t - t2)\right)$	$3 \le \alpha_t \le 4, 0.5T \le (t2 - t1) \le 3T$ $8ms \le \tau \le 30ms$
Sag with Harmonics	$x(t) = [A\left(1 - \alpha\left(u(t - t1) - u(t - t2)\right)\right)\sin(\omega t)] * [\alpha_1\sin(\omega t) + \alpha_3\sin(3\omega t) + \alpha_5\sin(5\omega t) + \alpha_7\sin(7\omega t)]$	$0.1 \le \alpha \le 0.8, T \le (t2 - t1) \le 9T$ $0.05 \le \alpha_3, \alpha_5, \alpha_7 \le 0.15, \alpha_1 = 1$
Swell with Harmonics	$x(t) = [A\left(1 + \alpha\left(u(t - t1) - u(t - t2)\right)\right)\sin(\omega t)] * [\alpha_1\sin(\omega t) + \alpha_3\sin(3\omega t) + \alpha_5\sin(5\omega t) + \alpha_7\sin(7\omega t)]$	$0.1 \le \alpha \le 0.8, T \le (t2 - t1) \le 9T$ $0.05 \le \alpha_3, \alpha_5, \alpha_7 \le 0.15, \alpha_1 = 1$
Interruption with Harmonics	$x(t) = [A\left(1 - \alpha\left(u(t - t1) - u(t - t2)\right)\right)\sin(\omega t)] * [\alpha_1\sin(\omega t) + \alpha_3\sin(3\omega t) + \alpha_5\sin(5\omega t) + \alpha_7\sin(7\omega t)]$	$0.9 \le \alpha \le 1, T \le (t2 - t1) \le 9T$ $0.05 \le \alpha_3, \alpha_5, \alpha_7 \le 0.15, \alpha_1 = 1$

IV. GENERATION OF POWER QUALITY DISTURBANCES USING MATLAB

The steps involved in the software program developed in MATLAB for the generation of power quality disturbances using the integral mathematical models are represented in the form of flow chart shown in figure 1.

In this paper, the implementation of integral mathematical models of eleven power quality disturbances which are represented in the form of parametric equations is done using the software program developed in MATLAB software. Total eleven power quality disturbances are generated, namely voltage sag, voltage swell, voltage interruption, harmonics, voltage flicker, voltage notch, impulsive transient, oscillatory transient, voltage sag with harmonics, voltage swell with harmonics, and voltage interruption with harmonics. Figure 2 shows the pure 50Hz sine wave of amplitude 1pu and time duration 0.4 sec generated using the parametric equation.

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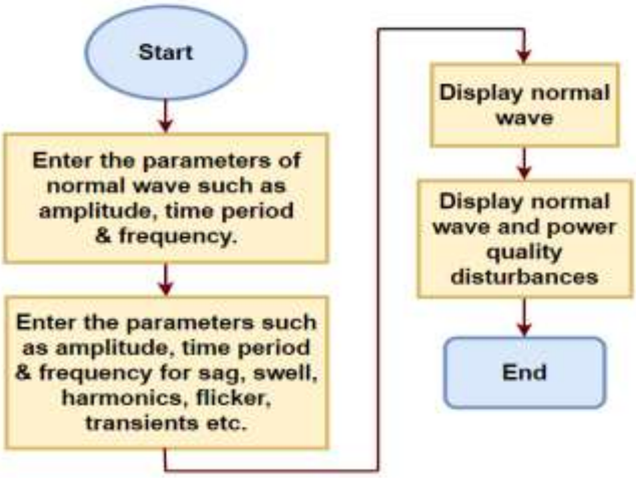

Fig. 1 Flow Chart for generation of power quality disturbances

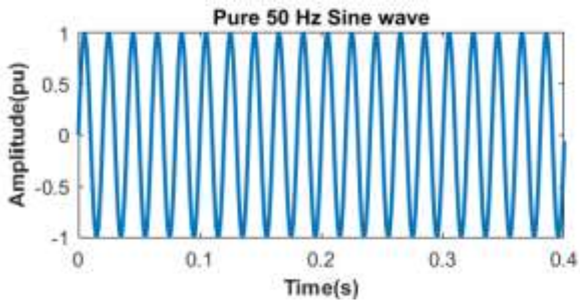

Fig. 2 Pure 50Hz sine wave generated using the parametric equation

Figure 3 shows the voltage signal with a sag of 50% for time duration 0.2 sec generated by controlling the parameters of the parametric equation. The total duration of the waveform is 0.4 sec.

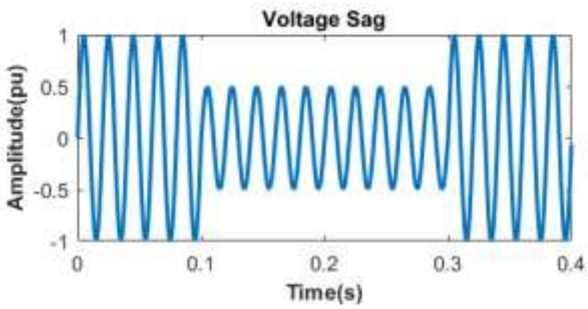

Fig. 3 Voltage Sag waveform generated using the parametric equation

Figure 4 shows the voltage signal with a swell of 150% for time duration 0.2 sec generated by controlling the parameters of the parametric equation. The total duration of the waveform is 0.4 sec.

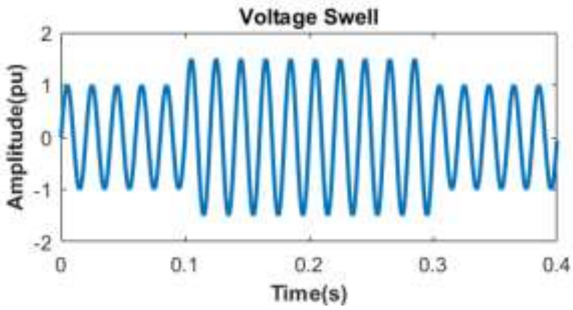

Fig. 4 Voltage Swell waveform generated using the parametric equation

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Figure 5 shows the voltage signal with an interruption for time duration 0.2 sec generated by controlling the parameters of the parametric equation. The total duration of the waveform is 0.4 sec.

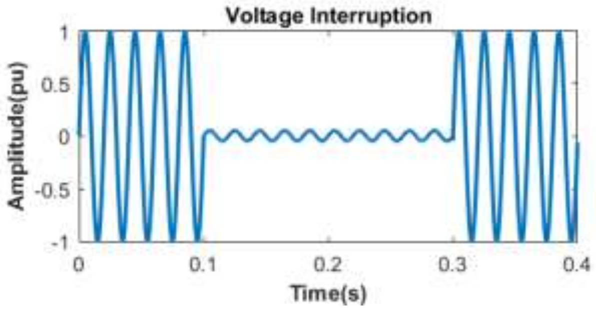

Fig. 5 Voltage Interruption waveform generated using the parametric equation

Figure 6 shows the voltage signal with odd harmonics for time duration 0.4 sec generated by controlling the parameters of the parametric equation. The total duration of the waveform is 0.4 sec.

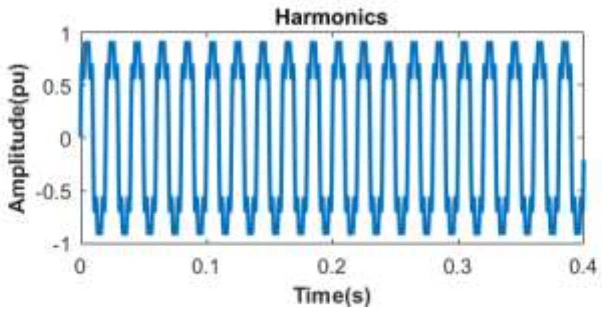

Fig. 6 Harmonics waveform generated using the parametric equation

Figure 7 shows the voltage signal with impulsive transient with a positive peak of 1.4 pu and a negative peak of 2 pu for a time duration in music generated by controlling the parameters of the parametric equation. The total duration of the waveform is 0.4 sec.

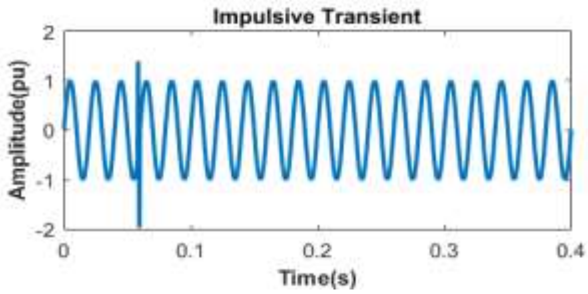

Fig. 7 Impulsive Transient waveform generated using the parametric equation

Figure 8 shows the voltage signal with oscillatory transients of frequency 300 to 900Hz and time duration 0.06 sec generated by controlling the parameters of the parametric equation. The total duration of the waveform is considered to be 0.1 sec for better visualization of the waveform.

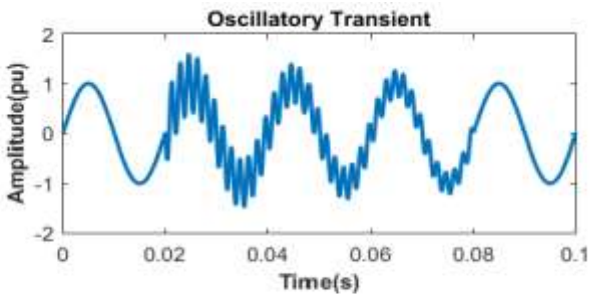

Fig. 8 Oscillatory Transient waveform generated using the parametric equation

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Figure 9 shows the voltage signal with flicker for time duration 0.4 sec generated by controlling the parameters of the parametric equation.

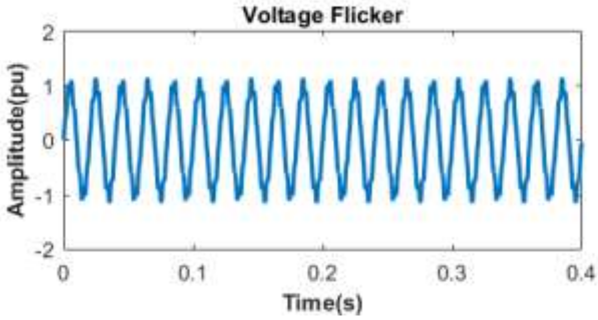

Fig. 9 Voltage Flicker waveform generated using the parametric equation

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

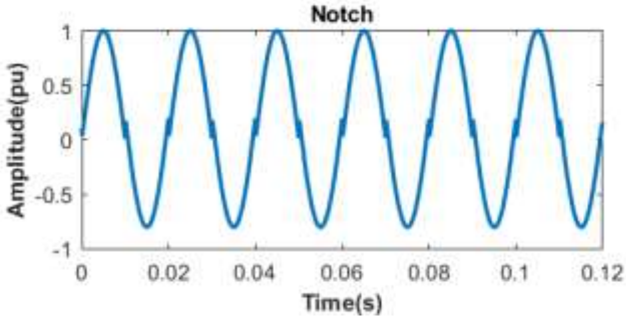

Fig. 10 Voltage Notch waveform generated using the parametric equation

Figure 11 shows the voltage signal with the sag of 50% along with harmonics for time duration 0.4 sec generated by controlling the parameters of the parametric equation.

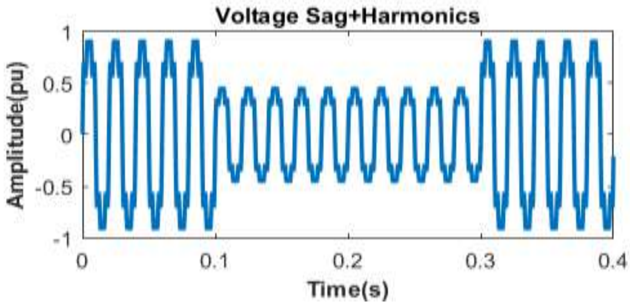

Fig. 11 Voltage Sag + Harmonics waveform generated using the parametric equation

Figure 12 shows the voltage signal with the swell of 150% along with harmonics for time duration 0.4 sec generated by controlling the parameters of the parametric equation.

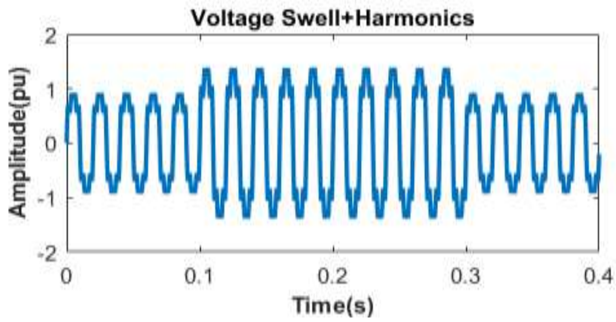

Fig. 12 Voltage Swell + Harmonics waveform generated using the parametric equation

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

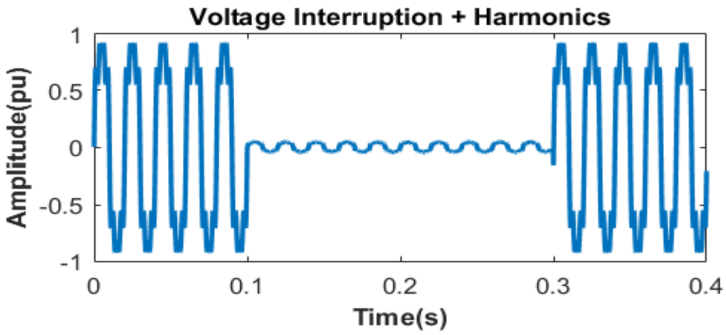

Fig. 13 Voltage Interruption + Harmonics waveform generated using the parametric equation

V. CONCLUSION

In this paper, the implementation of the integral mathematical models of power quality disturbances is done in the form of the parametric equation using the software program developed in MATLAB. Generation of both single and multiple power quality disturbances is done as per the parameters defined by IEEE1159 and IEC61000 standards. The power quality disturbance signals generated using the integral mathematical models will be useful in the research of detection and classification of power quality disturbances. Researchers working in the field of power quality can use mathematical models to generate the synthetic PQ signals and the data set required for training, validation, and testing the algorithms used for detection and classification PQDs. This will help in testing the feasibility of the algorithms, which signifies the importance of implementing the integral mathematical models of power quality disturbances. This work is of special interest in the initial stage of research which will reduce the effort and time spent on algorithm development.

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 & 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 Umamani Subudhi. “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]. 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).
[7]. V. Janahiraman, Tiagrajah & Bala, Prakash, “An Ensemble Classifier based Power Quality Disturbances Classification,” 9. 4161-4167. 10.35940/ijeat. B4924.129219 (2019).
[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]. S. Khokhar, A.A.M. Zin, A.S. Mokhtar, N. Ismail, "MATLAB/Simulink based modeling and simulation of power quality disturbances," in Proc. IEEE Conf. on Energy Conversion (CENCON), Johor Bahru, pp. 445-450, 2014.