Generation of Power Quality Disturbances Required for the Performance Assessment of Different Power Quality Monitoring Algorithms using Multiple Approaches

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Abstract: *This paper presents multiple approaches for the generation of Power Quality Disturbances (PQDs) and the development of the dataset required for evaluating the effectiveness of various PQDs detection and classification algorithms. In today's power networks, power quality is an important issue. Three PQDs, namely the voltage sags, swells, and interruptions, are considered under study in this research paper. In today's electricity grid, these PQDs are thought to be more prevalent and common. Today's end-users demand high-quality supply for the operation of their sensitive equipment. The utility must keep an eye on PQ and take the required actions to maintain it in order to deliver a supply of high quality. The creation of reliable and efficient PQ monitoring algorithms is a major goal for many budding researchers. The PQD signals or dataset of PQDs are required for the development and performance assessment of these PQ monitoring algorithms. The different approaches available for the generation of PQDs and dataset are discussed in detail in this research paper. This research work focuses on generating PQDs through the use of MATLAB programming, simulation of PQD models in the MATLAB Simulink environment, and experimental methodology. This paper will serve as a useful resource for budding researchers working in the PQ domain.*

Keywords: Power Quality Disturbances, Power Quality, Power Quality Monitoring Algorithms, Classification.

I. INTRODUCTION

Power quality has become more significant in the current era of research and technology. Power quality is currently a concern for utilities and customers alike. Non-linear loads, power electronic load/converters, solid-state devices, unbalanced loads, computer systems, and data processing units are being used more frequently, which is the main cause of the power quality problems [1]. Power quality problems are mostly caused by the usage of distributed generation systems based on renewable energy resources and power electronic converters [2]. The most frequent disruptions in power systems include voltage sag, voltage swell, interruption, harmonics, transients, and flicker [3]. Modern equipment connected to the power system may get affected due to exposure to PQDs occurring in the power system due to any reason [5]. Therefore, it is essential to precisely classify power quality disturbances when they occur. Understanding the qualities and characteristics of power quality disturbances is crucial for carrying out the task of detection, classification, and characterization. This paper deals with the generation of three PQDs namely voltage sag, swell, and interruptions using multiple approaches.

II. POWER QUALITY DISTURBANCES

Power quality is defined in a number of ways. Power quality is defined differently by different international standard organisations. 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”.

Economic value is the main factor driving our interest in power quality. Utilities, their clients, and suppliers of load equipment all experience economic impacts.

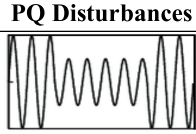
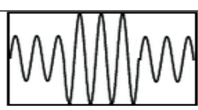
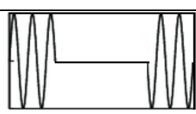
Many industrial consumers may experience immediate financial consequences of the power quality. Recently, there has been a lot of focus on reviving industry with increased automation and cutting-edge machinery. This typically refers to equipment that is electronically controlled, efficient in terms of energy use, and frequently considerably more susceptible to variations in the supply voltage than its electromechanical counterparts.

Customer equipment malfunctions could be brought on by power quality problems. It might result in the production process being interrupted, causing the product to be harmed and the manufacture to be hindered, which would result in financial loss. The supply quality needs to be good for the electric and electronic equipment to operate properly. Table 1 shows the characteristics and table 2 shows the causes and effects of the three PQDs under study.

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

Table II: 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.

III. MULTIPLE APPROACHES FOR GENERATION OF POWER QUALITY DISTURBANCES

3.1 Generation of Power Quality Disturbances using Integral Mathematical Models

The integral mathematical models of PQDs represented by parametric equations are used to generate the PQDs. By altering the values in parametric equations, the magnitude and period of the disturbances can be adjusted. These mathematical models are employed to produce the synthetic PQ data. This will facilitate the correct representation of the real-time PQ signals. The generated synthetic PQ signals will be identical to the real-time signals [2]. PQ signals are necessary for determining the effectiveness of the algorithms used for detecting and classifying PQDs. The software code for the development of synthetic PQ signals must therefore be appropriately modelled and implemented.

In this research work, we have generated three PQDs namely voltage sag, voltage swell, and interruption by implementing the parametric equations based integral mathematical models using MATLAB programming. These events' amplitudes are regulated by the parameter A, while their durations are controlled by the time constants t_1 and t_2.The parametric equations for the three PQDs are shown in Table 3.

Table III: Parametric Equations of Power Quality Disturbances

PQDs	**Equations**	**Parameters**
Voltage Sag	$x(t) = A\left(1 - \alpha\left(u(t - t1) - u(t - t2)\right)\right) \sin(\omega t)$	$0.1 \leq \alpha \leq 0.8, T \leq (t2 - t1) \leq 9T$
Voltage Swell	$x(t) = A\left(1 + \alpha\left(u(t - t1) - u(t - t2)\right)\right) \sin(\omega t)$	$0.1 \leq \alpha \leq 0.8, T \leq (t2 - t1) \leq 9T$
Voltage Interruption	$x(t) = A\left(1 - \alpha\left(u(t - t1) - u(t - t2)\right)\right) \sin(\omega t)$	$0.9 \leq \alpha \leq 1, T \leq (t2 - t1) \leq 9T$

3.2 Generation of Power Quality Disturbances using MATLAB Simulink Models

The Power Quality Disturbances such as voltage Sag, Swell and Interruption are generated using different MATLAB Simulink Models. Table 4 shows the configuration of Simulink models used for generation of PQDs.

Table IV: Configuration of Simulink Models used for Generation of Power Quality Disturbances

Components	**Parameters**
3-Phase Voltage Source	11kV, 400V, 50Hz, 1MVA
3-Phase Programmable Source	11kV, 400V, 50Hz, 1MVA
3-Phase Transformer	11kV/400V, 50Hz, 1MVA
3-Phase Active Load	500kW, 400V, 50Hz
3-Phase Reactive Load	100kVAR, 400V, 50Hz
Bus1	11 kV
Bus2	0.4 kV
Fault Resistance	1ohm
Breaker Resistance	0.001ohm, 1 MVA SC
Sampling Frequency	10 kHz

A. Generation of Voltage Sag

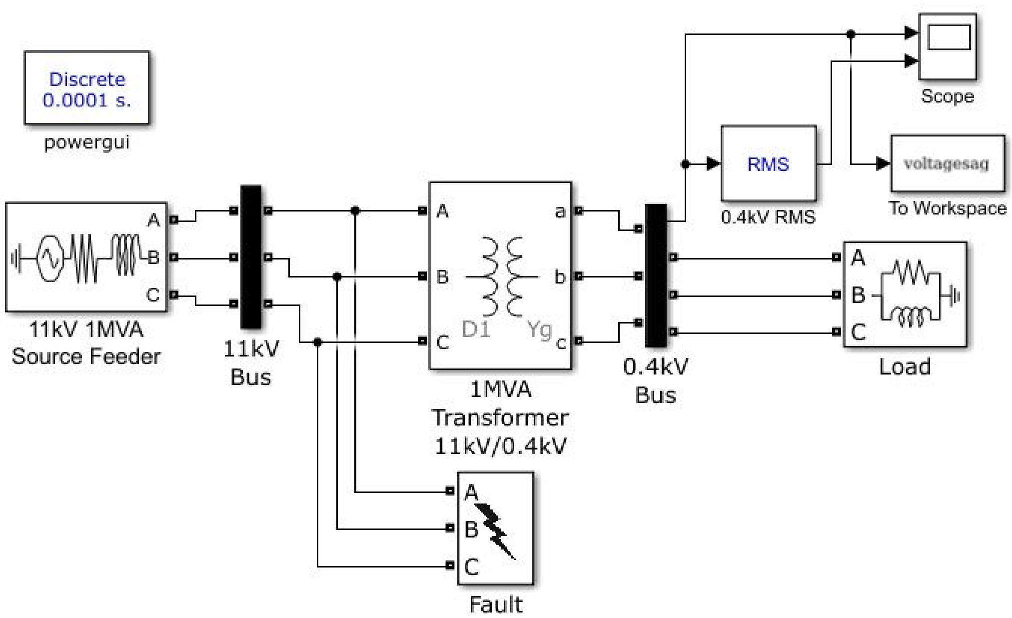


Fig. 1 MATLAB Simulink Model for Voltage Sag

Figure 1 shows the voltage sag model simulated in the MATLAB Simulink environment. This model consists of a three-phase AC voltage source representing a feeder, a three-phase step-down transformer, a three-phase load, and a three-phase fault block. The detailed configuration of all components is given in table 4. In order to generate the three-phase balanced voltage sag, a three-phase ground fault is simulated at an 11 kV bus. A three-phase to ground fault is created at the 11 kV bus in order to generate the three-phase balance voltage sag. A fault is created at 0.3 sec and cleared at 0.7 sec during this a voltage sag is observed at both 11 kV and 0.4 kV buses. By altering the fault resistance, the magnitude of this voltage sag can be changed. By altering the fault instant, multiple cases of voltage sag can be obtained.

B. Generation of Voltage Swell

Figure 2 shows the voltage swell model simulated in the MATLAB Simulink environment. This model consists of a three-phase programmable voltage source representing a feeder and three phase load. The detailed configuration of all components is given in table 4. In this model, the three-phase programmable source is programmed to vary the amplitude with respect to time in order to generate the three-phase balanced voltage swell at 0.4 kV bus. A voltage swell is created at 0.3 sec and sustained up to 0.7 sec. By altering the amplitude in a programmable source, the magnitude of this voltage swell can be changed. By altering the time duration, multiple cases of voltage swell can be obtained.

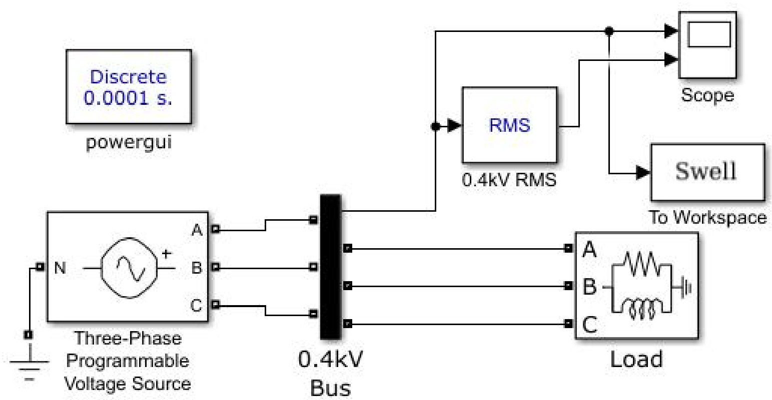


Fig. 2 MATLAB Simulink Model for Voltage Swell

C. Generation of Voltage Interruption

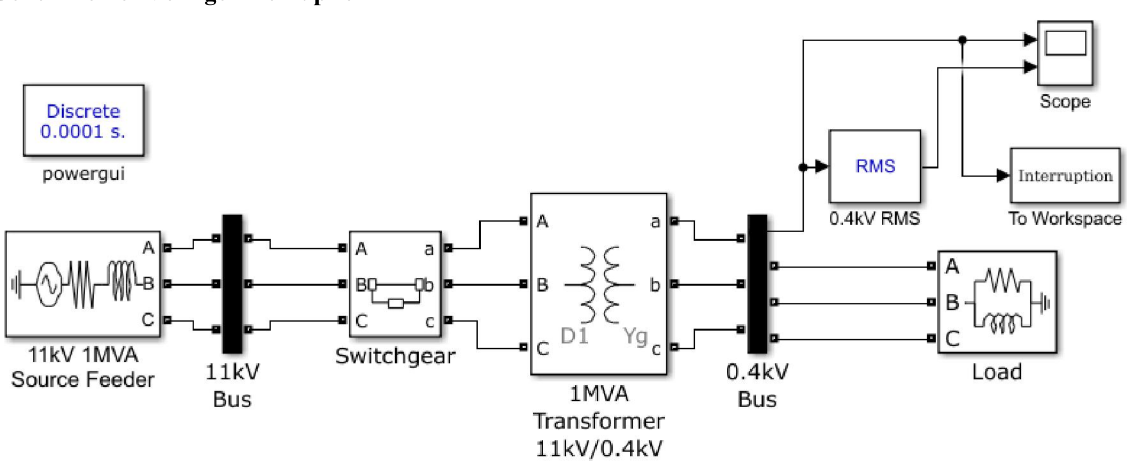


Fig. 3 MATLAB Simulink Model for Voltage Interruption

Figure 3 shows the voltage interruption model simulated in the MATLAB Simulink environment. This model consists of a three-phase AC voltage source representing a feeder, a three-phase circuit breaker, a three-phase step-down transformer, and three phase load. The detailed configuration of all components is given in table 4. In order to generate the three-phase voltage interruption, a three-phase circuit breaker in an 11 kV feeder is operated to interrupt the supply of the three-phase transformer. A circuit breaker is OPEN at 0.3 sec and CLOSED at 0.7 sec during this a voltage interruption is observed at 0.4 kV buses. By altering the breaker operation instant, multiple cases of voltage interruption can be obtained.

3.3 Generation of Power Quality Disturbances using Experimental Setup

In this research work, extensive experimentation is done in order to generate the PQDs. The experimental setup shown in figure 4 consists of a supply source, a custom-built 5KVA, 440V/440V, 50Hz three-phase isolation transformer, 3 HP three-phase induction motor, three-phase resistive load bank, operating circuit, voltage probes, data acquisition, and PC. The transformer carries external tapings on both primary and secondary winding, hence accessible for creating inter-turn faults. In this setup a voltage sag is created by switching ON the induction motor and creating an inter-turn fault on the transformer, a voltage swell is created by switching OFF heavy load and a voltage interruption is created by switching OFF the supply for a certain duration. The voltage signals corresponding to different PQDs were captured with the help of Tektronix made Digital Storage Oscilloscope (DSO) TPS 2014B and ADLINK DAQ. The DSO has four isolated channels with 100MHz bandwidth and is capable of sampling signals at the rate of 1Gsamples/second. The ADLINK DAQ has 10 input ports and 10 output ports. Each port has a maximum voltage rating of 10 volts. Tektronix make voltage probes are used to monitor the voltage. Figure 4 shows the block diagram of the data acquisition system.

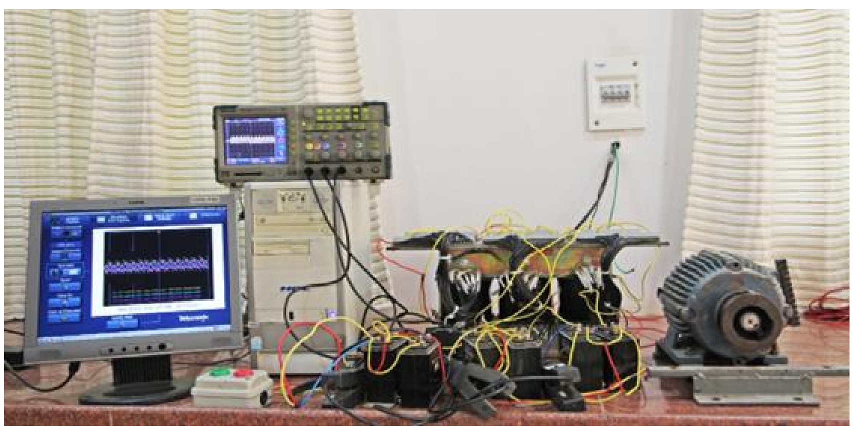


Fig. 4 Experimental setup for generation of PQDs

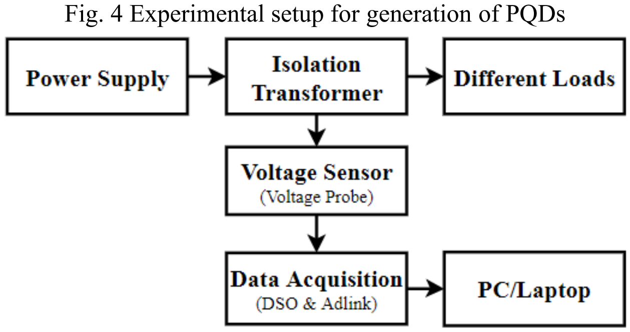


Fig. 5 Block diagram of Data Acquisition System

IV. Results and Discussion

This section describes the results of multiple approaches used for the generation of three power quality disturbances considered in this study.

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4.1 Results of PQDs Generated by Implementing Integral Mathematical Models in MATLAB

The integral mathematical models of PQDs represented by parametric equations are implemented using MATLAB programming in order to generate the three PQDs. The amplitudes of the PQDs are regulated by the parameter A, while their durations are controlled by the time constants t_1 and t_2. In this research work we have the value of A=326 which is the maximum value of the instantaneous waveform under three phase for which the RMS value found to be 400 V.

The voltage signal with a 50% sag for 0.4 seconds is shown in figure 6 which is generated by adjusting the parameters $\alpha=0.5$, $t_1=0.3$ and $t_2=0.7$. The total duration of the waveform is 1 sec.

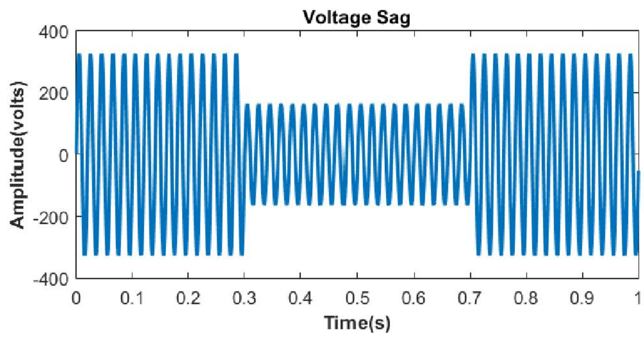

Fig. 6 Voltage Waveform with Sag

The voltage signal with a 150% swell for 0.4 seconds is shown in figure 7 which is generated by adjusting the parameters $\alpha=0.5$, $t_1=0.3$ and $t_2=0.7$. The total duration of the waveform is 1 sec.

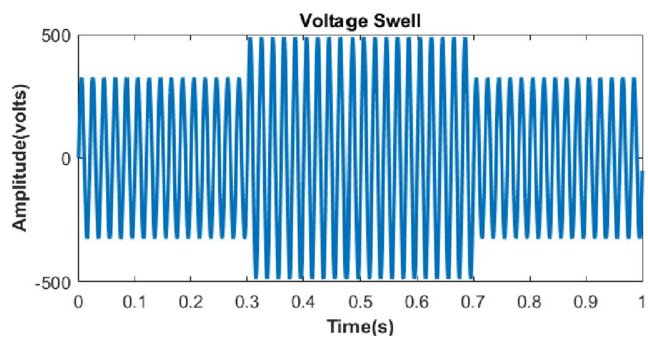

Fig. 7 Voltage Waveform with Swell

The voltage signal with an interruption for 0.4 seconds is shown in figure 8 which is generated by adjusting the parameters $\alpha=0.95$, $t_1=0.3$ and $t_2=0.7$. The total duration of the waveform is 1 sec.

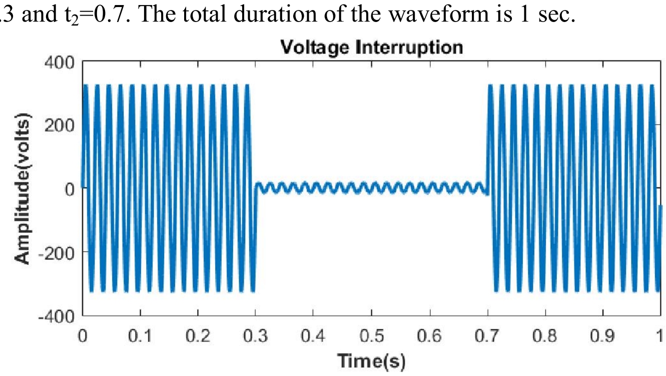

Fig. 8 Voltage Waveform with Interruption

4.2 Results of PQDs Generated using MATLAB Simulink Models

The simulation models of PQDs are used in the MATLAB Simulink environment to simulate PQDs like voltage sag, voltage swell, and voltage interruptions. A three-phase symmetrical fault is applied to the system to cause the voltage sag. On an 11kV bus, a three-phase to ground fault is created at 0.3 seconds and cleared in 0.7 seconds. Both the 11 kV and 0.4 kV buses experience a voltage sag during the fault duration. The simulation time is set to 1 sec. The amplitude and instant of the sag are altered to produce the required dataset. By changing the fault resistance, the amplitude is changed. Figure 9 shows the instantaneous and RMS voltage waveform with a sag of80 percent obtained from the MATLAB Simulink model.

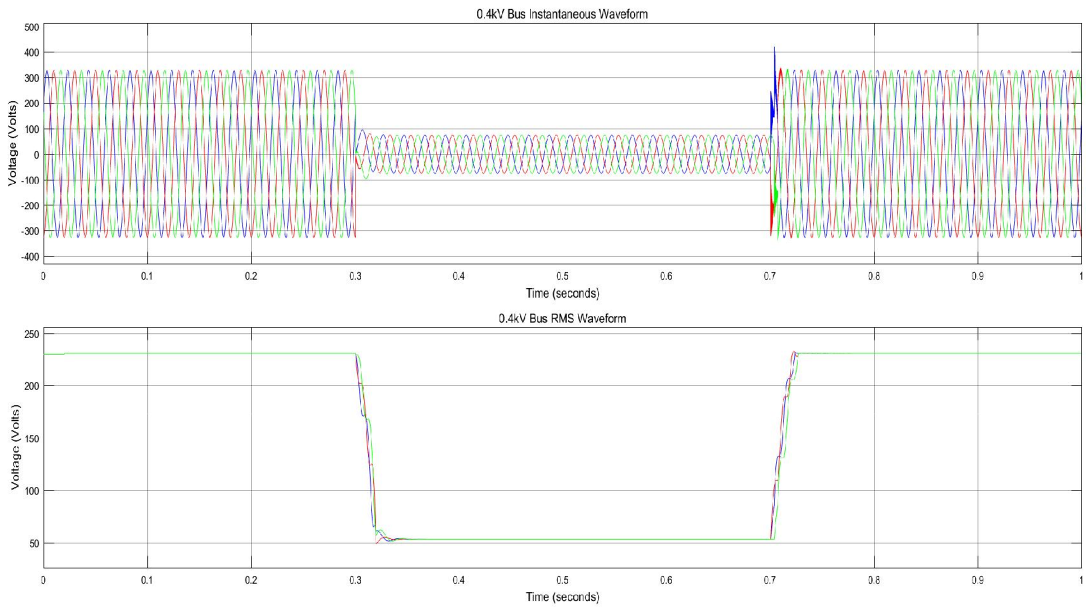

Fig. 9 Voltage Waveform with 80 % Sag

The voltage swell is obtained by modelling the swell model using programmable sources in the MATLAB Simulink environment. The event starts at 0.3 seconds and ends at 0.7 seconds. The simulation time is set to 1 sec. The amplitude and instant of the swell are altered to produce the required dataset. By changing the programmable source's parameters, the voltage swell's magnitude can be altered. Figure 10 shows the instantaneous and RMS voltage waveform with a swellof20 percent obtained from the MATLAB Simulink model.

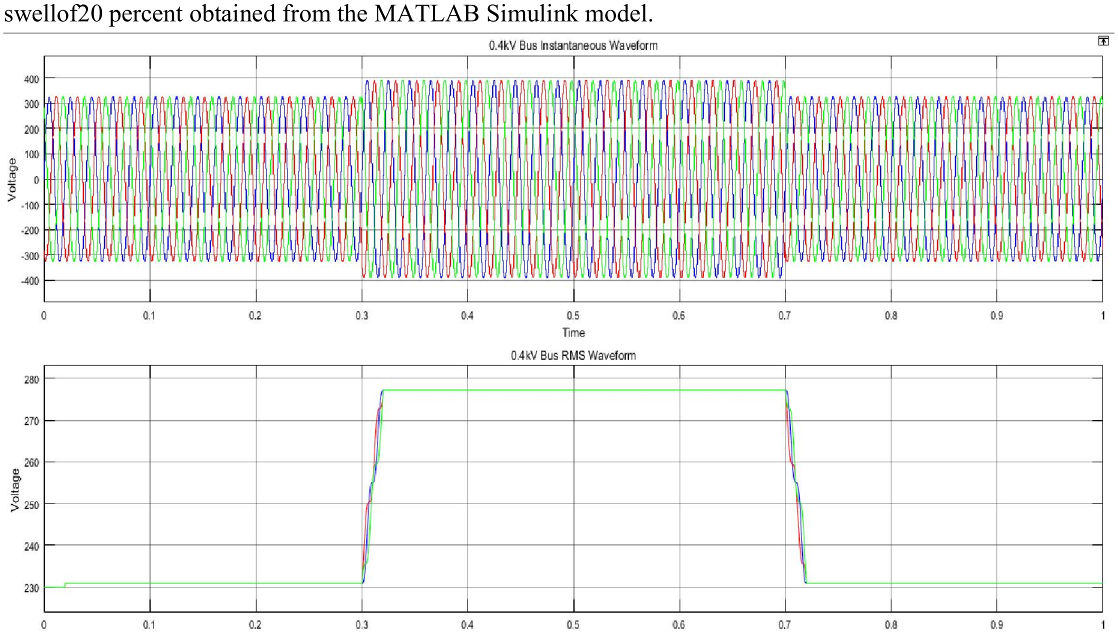

Fig. 10 Voltage Waveform with 20% Swell

The voltage interruption is obtained by modelling the interruption model in the MATLAB Simulink environment. By cutting off the supply with the aid of three-phase circuit breakers, the voltage interruption is accomplished. When the circuit breaker in the 11 kV feeder is turned off at 0.3 seconds and turned back on at 0.7 seconds, a voltage interruption is seen at the 0.4 kV bus. The simulation time is set to 1 sec. The instant of the interruption is altered to produce the required dataset. Figure 11 shows the instantaneous and RMS voltage waveform with an interruption obtained from the MATLAB Simulink model.

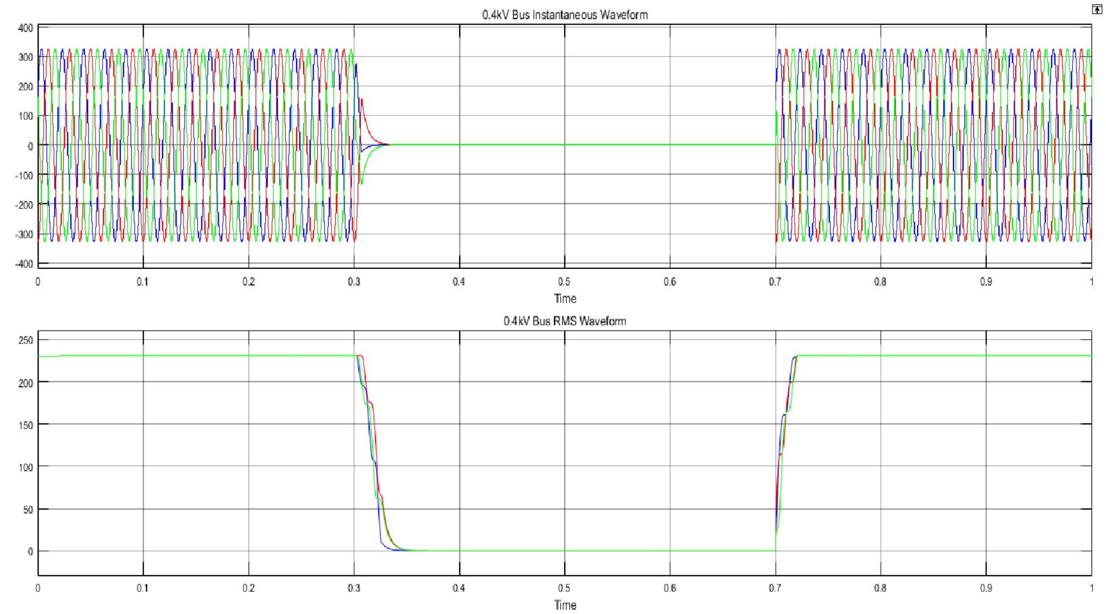

Fig. 11 Voltage Waveform with Interruption

4.3 Results of PQDs Generated using Experimental Setup

The Power Quality Disturbances are generated using the experimental setup developed in laboratory. Figure 12 shows the voltage waveform with 50 % sag generated by switching the three-phase induction motor and load. The voltage waveform is captured for a period of 1 second. The event starts at 0.3 sec and ends at 0.7 sec during this period a voltage sag is observed in the voltage waveform.

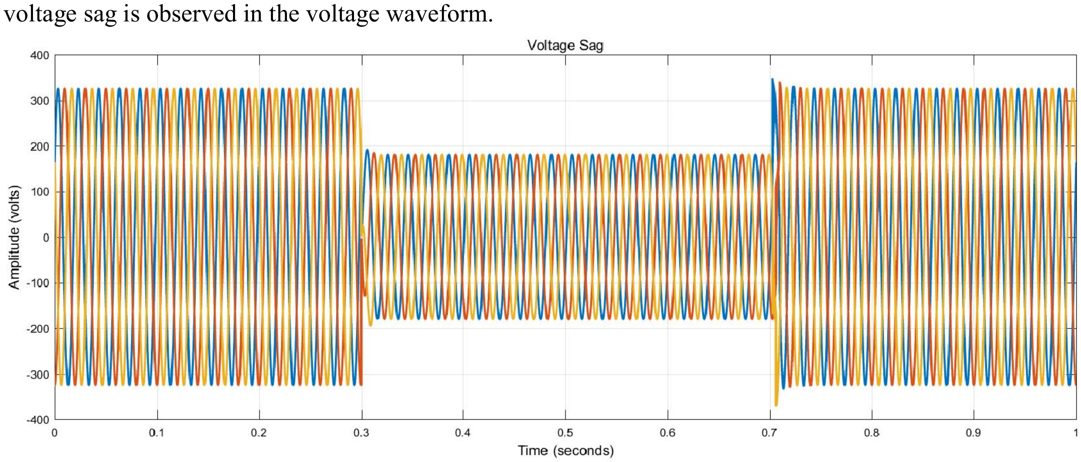

Fig. 12 Voltage Waveform with 50 % Sag

Figure 13 shows the voltage waveform with 20 % swell generated by switching OFF the heavy load. The voltage waveform is captured for a period of 1 second. The event begins at 0.3 sec and ends at 0.7 sec during this period a voltage swell is observed in the voltage waveform.

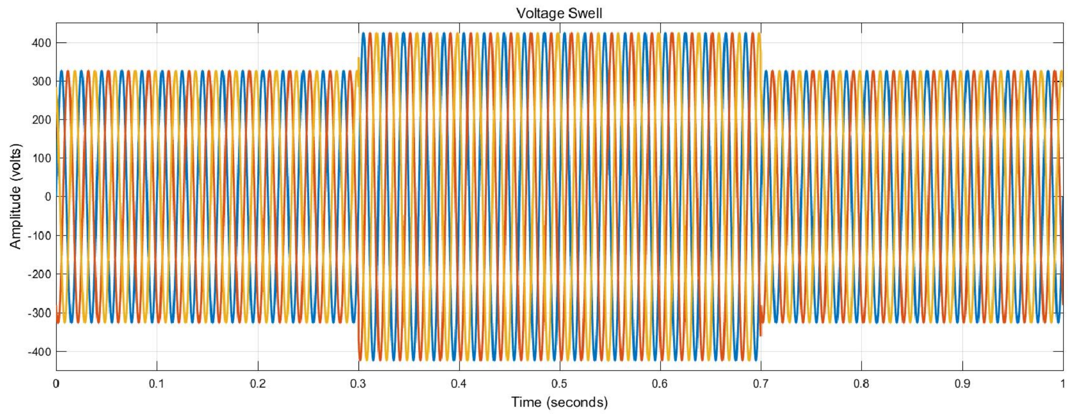

Fig. 13Voltage Waveform with 20% Swell

Figure 14 shows the voltage waveform with momentary interruption generated by switching OFF the power supply. The voltage waveform is captured for a period of 1 second. The event begins at 0.3 sec and ends at 0.7 sec during this period a voltage interruption is observed in the voltage waveform.

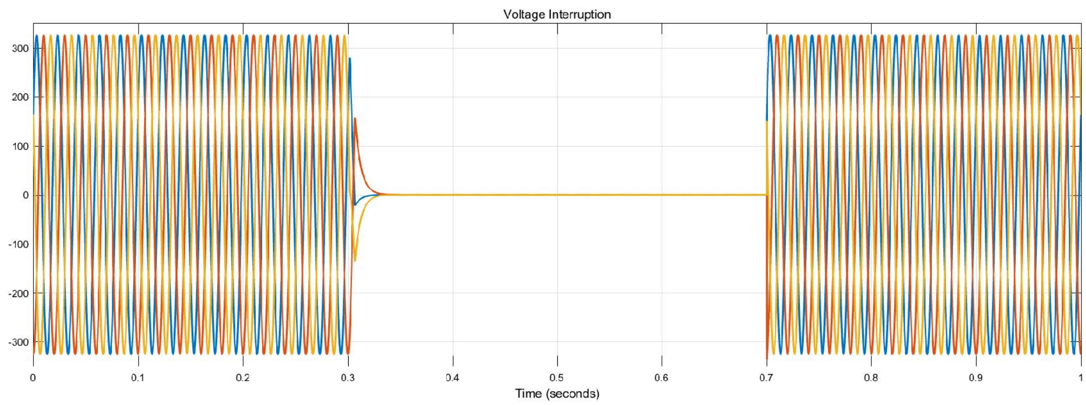

Fig. 14 Voltage Waveform with Interruption

V. CONCLUSION

In this study, we explore in depth the multiple methods for generating the Power Quality Disturbances (PQDs) needed for testing the performance of different PQDs detection and classification algorithms. The primary objective of this research is to generate the PQDs by implementing the integral mathematical models through MATLAB programming, simulation of PQD models in the MATLAB Simulink environment, and by developing the experimental setup. Voltage sag, voltage swell, and voltage interruption are the three PQDs that are being studied in this research work. The characteristics of the power quality disturbances generated using the multiple approaches shown in the result section are found to satisfy the standards of power quality. These generated PQDs are further used to generate the dataset required for testing the performance of different power quality detection and classification algorithms. The performance of the power quality monitoring system can be enhanced by conducting multiple testing's using multiple PQDs. The suggested approach allows for the generation of both single and multiple power quality disturbances that meet the requirements of the IEEE1159 and IEC61000 standards. The research on the detection and classification of power quality disturbances will benefit from the power quality disturbance signals generated utilizing the suggested methods. These methods can be utilized by researchers working in the power quality domain to generate the PQDs and dataset needed for training, validating, and testing the algorithms used for PQDs detection and classification. This will assist in evaluating the algorithms' viability, underscoring the significance of the suggested methods for generating PQDs. This work is particularly interesting at the beginning of the research process since it will shorten the time and effort required for algorithm development.

REFERENCES

[1]. R. S. Kankale, S. R. Paraskar, and S. S. Jadhao, “Implementation of Integral Mathematical Models of Single and Multiple Power Quality Disturbances,” vol. 8, no. 6, pp. 330–336, 2021, doi: 10.17148/IARJSET.2021.8657.

[2]. 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.

[3]. 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.

[4]. Ankita Dandwate & 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).

[5]. 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.

[6]. Rodney H.G. Tan and Vigna K. Ramachandaramurthy “A Comprehensive Modeling and Simulation of Power Quality Disturbances Using MATLAB/SIMULINK” 10.5772/61209.

[7]. P. V. Dhote, B. T. Deshmukh and B. E. Kushare, "Generation of power quality disturbances using MATLAB-Simulink," 2015 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC), 2015, pp. 0301-0305, doi: 10.1109/ICCPEIC.2015.7259479.

[8]. B. Velkovski and Z. Kokolanski, "A Virtual Signal Generator for Real-Time Generation of Power Quality Disturbances," 2020 XXIX International Scientific Conference Electronics (ET), 2020, pp. 1-4, doi: 10.1109/ET50336.2020.9238243.

[9]. M. Simić, D. Denić, D. Živanović, D. Taskovski and V. Dimcev, "Generation of the power quality disturbances in LabVIEW software environment," 2011 10th International Conference on Telecommunication in Modern Satellite Cable and Broadcasting Services (TELSIKS), 2011, pp. 593-596, doi: 10.1109/TELSKS.2011.6143184.

[10]. Khadse, Chetan & Chaudhari, Madhuri &Borghate, V.B. (2016). A laboratory set-up for power quality disturbance generator and real time power quality monitoring. 61-64. 10.1109/WIECON-ECE.2016.8009088.