DATA EXTRACTION FOR CLASSIFICATION AND CHARACTERIZATION OF POWER QUALITY PROBLEMS

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Abstract: *The importance of power quality is increasing day by day because of the noticeable great damage caused by power quality disturbances like malfunctioning and failure of the equipment of public or industrial facilities. So, in order to improve the power quality, the sources of power quality disturbances should be known before appropriate mitigating action can be taken. To achieve this, the paper presents a detailed classification and characterization of voltage sag, swell, unbalance and interruption problems. For the problem detection, a simple method of RMS voltage calculation over a window of half cycle is used. The RMS voltage samples are obtained and the data extraction process is carried out to get the power quality problem samples out of this huge samples. Then the MATLAB programming is used to classify and characterize the problems. The program outputs are shown for the input of actual RMS voltage samples and the extracted samples.*

Keywords: *Characterization; Classification; Data Extraction; Identification; Power quality problems; RMS.*

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I. INTRODUCTION

An electrical power system is expected to deliver continuous power with undistorted sinusoidal rated voltages and currents at rated frequency to the end users. However, due to large penetration of power electronic based controllers and devices along with restructuring of the electric power industry and small-scale distributed generation have put more stringent demand on the quality of electric power supplied to the customers. A power quality problem is any occurrence manifested in voltage, current, or frequency deviation that results in failure or mis-operation of customer equipment [1]. In early days, power quality problems were concerned with the power system transients arising due to switching and lightning surges, induction furnace and other cyclic loads. Increased interconnection, widespread use of power electronic devices with sensitive and fast control schemes in electrical power networks have brought many technical and economic advantages, but these have also introduced new challenges for the power engineers [2].

In new electricity market scenarios, now electricity consumers can shift to the new service providers, if power quality is not good. Moreover, these customers can demand a higher quality of service. The utilities or other electric power providers have to ensure a high quality of their service to remain competitive and to retain/attract the customers [3]. For the improvement of power quality, it is first required to know the sources of power quality disturbances and then take necessary actions to mitigate them. This can be achieved by detection of different power system disturbances. The detected disturbances are subsequently classified and information describing localization, duration and type of the disturbance is reported.

The classical major steps for classification of power quality problems are feature extraction and classification. Feature extraction is generally used when there is a need to extract specific information from the raw data, which is typically voltage and current waveforms in a power system. The feature extraction of signals can be performed by direct techniques, such as the RMS value of the raw samples, or transformation techniques, such as the Fourier transform, the wavelet transform and S-transform. S-transform can be considered either as an extension of Wavelet Transform or a variable window Short-Time Fourier Transform which is more superior to these two. In recent years, S-transform has been used to classify power-quality disturbances combined with other pattern classifiers such as Artificial Neural

Networks (ANN), Fuzzy Logic (FL), Support Vector Machines (SVM) or rule-based decision tree [4-9]. All these methods have same process of doing first ST to the unknown disturbance signal and then using different classifiers to find the disturbances. But these two processes and algorithms are very complicated and they are difficult to make the analysis quantitative.

The data originated in power systems can be raw waveforms (voltages and currents) sampled at relatively high sampling frequencies, pre-processed waveforms (e.g., RMS) typically sampled at low sampling frequencies and status variables (e.g., if a relay is opened or closed) typically sampled at low sampling frequencies [10]. This data will be huge to be handled directly for the classification process. Hence, there is a need to first extract the relevant data samples containing power quality problems and then process. This extracted data can be used further for the classification of power quality problems and for characterizing the problems.

In this paper, data extraction technique is implemented by using Microsoft Office Excel by writing simple logical functions. The data extracted is provided for the classification and characterization of power quality problems. A simple algorithm is written to classify in detail all the categories of voltage sags, swells, interruptions, unbalance problems and to give the number of occurrences of similar kind of problems. The algorithm also provides the characteristics of magnitude and duration of the power quality problems. This algorithm is implemented & tested using MATLAB software.

The paper is organized as follows: Characteristics of power quality problems such as sag, swell, unbalance and interruption along with the formula used for RMS calculations are discussed in Section II. Section III deals with the algorithm developed for classification and characterization of power quality problems. Section IV shows the MATLAB simulation model used for generating the data for various power quality problems. The test results and discussions of the program written in MATLAB are given in Section V and Section VI concludes the paper.

II. CHARACTERISTICS OF POWER QUALITY PROBLEMS

Voltage sag, swell and interruption are mainly characterized by its magnitude and duration. The voltage unbalance is characterized by unbalance percentage and duration. The magnitude is defined as the voltage during the event and the duration is defined as the time between the commencement and clearance of the event [11]. In order to find any solution for voltage sag, swell, interruption & unbalance problems, it is necessary to identify its characteristics.

A. Voltage Sag Characteristics

Voltage Sag is defined as a decrease in RMS voltage between 0.1 p.u. to 0.9 p.u. at the power frequency for durations of 0.5 cycles to 1 minute, reported as the remaining voltage [12]. Voltage sags are usually associated with system faults but can also be caused by energization of heavy loads or starting of large motors. The sag magnitude in case of a three phase system is the minimum RMS voltage during the sag if the sag is symmetrical and for unsymmetrical sag, the phase with the lowest remaining voltage is used to characterize the sag. The duration of voltage sag is the amount of time during which the voltage magnitude is below threshold and is typically chosen as 90% of the nominal voltage magnitude. For measurements in the three-phase systems, the three RMS voltages have to be considered to determine the duration of the sag. The voltage sag starts when at least one of the RMS voltages drops below the sag-starting threshold. The sag ends when all three voltages have recovered above the sag ending threshold [13].

B. Voltage Swell Characteristics

Voltage Swell is defined as an increase in RMS voltage between 1.1 p.u. and 1.8 p.u. at the power frequency for durations from 0.5 cycles to 1 minute. Voltage sags and swells are usually associated with system fault conditions, but voltage swells are not as common as voltage sags. One way that a swell can occur is from the temporary voltage rise on the unfaulted phases during an SLG fault. Swells can also be caused by switching off a large load or energizing a large capacitor bank. Swells are characterized by their magnitude (RMS value) and duration.

C. Voltage Interruption Characteristics

An interruption occurs when the supply voltage decreases to less than 0.1 p.u. for a period of time not exceeding 1 min. Interruptions can be the result of power system faults, equipment failures, and control malfunctions. The interruptions are measured by their duration since the voltage magnitude is always less than 10 percent of nominal.

D. Voltage Unbalance Characteristics

Voltage Unbalance is sometimes defined as the maximum deviation from the average of the three phase voltages, divided by the average of the three phase voltages, expressed in percent. The primary source of voltage unbalances of less than 2 percent is single-phase loads on a three-phase circuit. Voltage unbalance can also be the result of blown fuses in one phase of a three-phase capacitor bank. Severe voltage unbalance (greater than 5 percent) can result from single-phasing conditions. The percentage voltage unbalance is given as:

$$\%\text{Voltage unbalance} = 100 * \frac{\text{Maximum voltage deviation from average voltage}}{\text{Average voltage}} \qquad (1)$$

The magnitude of the 3 phase voltages can be determined in a number of ways. The most common method is to obtain the sag magnitude from the RMS voltage by monitoring the data. There are several alternative ways of quantifying the voltage level. Two obvious are the magnitude of the fundamental component of the voltage and the peak voltage over each cycle or half cycle. But the RMS voltage is a quantity commonly used in power systems as an easy way of accessing and describing power system phenomena. The RMS value can be computed each time a new sample is obtained but generally these values are updated each cycle or half cycle. If the RMS values are updated every time a new sample is obtained, then the calculated RMS series is called continuous [14]. In this paper, RMS values are continuously calculated for a window of half cycle for more accuracy [15]. The formula given in equation (2) is used for the calculation of RMS values:

$$V_{rms}(k) = \sqrt{\frac{\sum_{i=k-N+1}^{i=k} v(i)^2}{N}} \quad \text{for } k \geq N$$

$$= V_{rms}(N) \qquad \text{for } k < N \qquad (2)$$

N is the window length of one half cycle and k is the time stamp which is restricted to be an integer that is equal to or greater than 1. Each k^{th} value of RMS voltage is obtained from N-1 previous samples and the current k^{th} sample. Here, the first (N-1) RMS voltage values have been made equal to the value for sample N. It is due to data window limitation and data truncation and couldn't be avoided.

III. CLASSIFICATION AND CHARACTERIZATION OF POWER QUALITY PROBLEMS

The process starts with the measurement and sampling of three phase RMS voltages (V_{arms}, V_{brms}, V_{crms}) at the Point of Common Coupling (PCC). From the large number of RMS voltage samples obtained, poor power quality samples are extracted using logical equations based on standard definitions of power quality. The samples extracted are given to the proposed algorithm for the classification & characterization of problems.

Proposed Algorithm:

1. For ($V_{arms} = V_{brms} = V_{crms}$), go to step 2 else go to step 5.
2. For ($V_{arms} \leq 0.9*V_{ref}$), obtain sag time duration & voltage magnitude to determine the type of sag. Count the number of occurrences of a similar type.
3. For ($V_{arms} \geq 1.1*Vref$), obtain swell time duration & voltage magnitude to determine the type of swell. Count the number of occurrences of a similar type.
4. For ($V_{arms} < 0.1*V_{ref}$), obtain interruption time duration & voltage magnitude to determine the type of interruption. Count the number of occurrences of a similar type.
5. For ($V_{arms} \neq V_{brms} \neq V_{crms}$), obtain unbalance time duration, voltage magnitudes & determine the unbalance percentage. Count the number of occurrences of voltage unbalance.
6. Repeat the steps 1 to 5 till all the samples are completed.
7. Display the type of power quality problems occurring along with its magnitude, duration and number of occurrences.

The algorithm checks the magnitude of the voltage signals. Under any power quality problem, depending on the magnitude level and time duration, it gives the information about the type of power quality problem/s, the number of times they are occurring in a given period and their characteristics. This algorithm is constructed using simple logic based on standard definitions [16] and is easily coded and executed using MATLAB programming. The proposed algorithm can be used for the detailed classification & characteristics of four major power quality problems like sag, swell, unbalance and interruption.

IV. SIMULATION MODEL

A simulation model as shown in Fig. 1 is used for the analysis of power quality problems. The circuit consists of a 33/11 kV distribution substation connected to a 2 km distribution line having a 11/0.433 kV distribution transformer supplying to a load of 190 kW, 140 kVAR [17]. The system is modelled using Simulink and SimPower System utilities of MATLAB. It is simulated to get the data for voltage sag, swell, unbalance and interruption problems. The voltage sag is created by a 3-phase to ground fault with varying fault impedance for different type of sags. The voltage swell is created by introducing capacitors. The voltage unbalance is created by a 3-phase unbalance fault. The interruption is introduced by creating a 3-phase to ground fault. The 3-phase RMS voltages are calculated at PCC and are sampled at a frequency of 2 kHz.

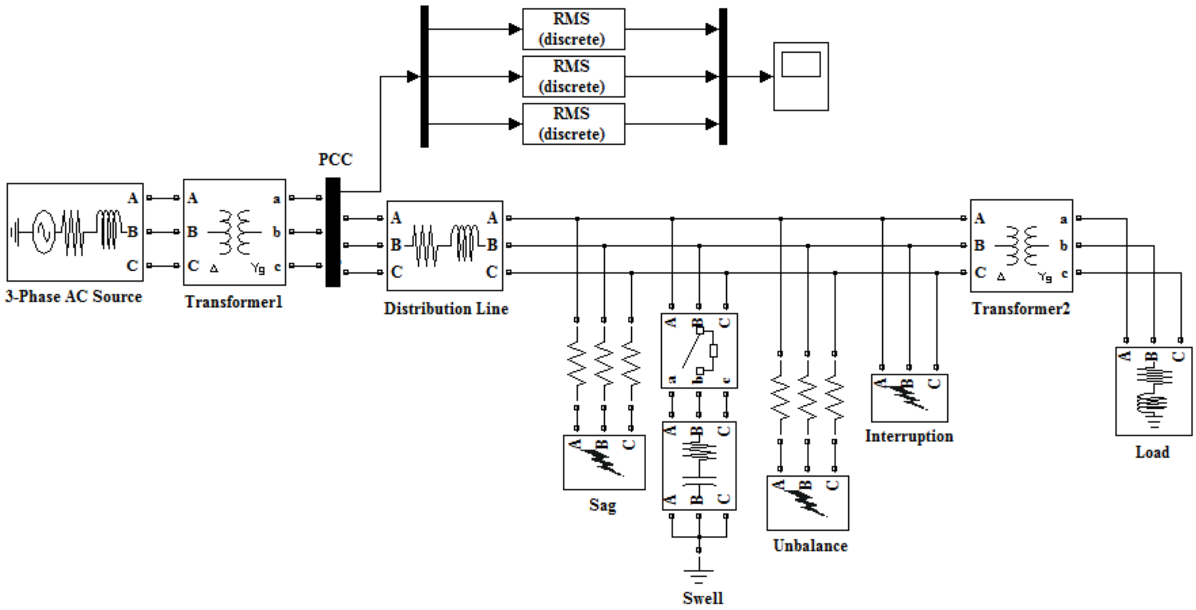

Fig. 1. Simulation Circuit of the test System

V. RESULTS AND DISCUSSION

To test the algorithm written, simulation circuit shown in Fig. 1 is simulated for different power quality problems like sags, interruptions, swell and unbalance. Two types of sags, two interruptions, one swell and an unbalance condition are created. Temporary sag of 0.4 p.u. (2569 V) for 4 sec (8000 samples) and momentary sag of 0.54 p.u. (3459 V) for 1 sec (2000 samples) are created. An unbalance of 15.4 % is created with the three phase voltages being 0.55 p.u. (3488 V), 0.63 p.u. (4032 V) and 0.74 p.u. (4704 V) for a duration of 2 sec (4000 samples). Two instantaneous interruptions with 0.5 sec (1000 samples) and 0.25 sec (500 samples) duration are created. A swell is created with 1.24 p.u. (7898 V) of magnitude and 1 sec (2000 samples) duration.

Fig. 2 shows the generated 3-phase RMS voltage samples at PCC which includes the power quality problems under consideration. The total number of samples obtained is 150000. Data extraction technique is used on this large number of samples to extract the required poor power quality samples using the logic function written in Microsoft Excel.

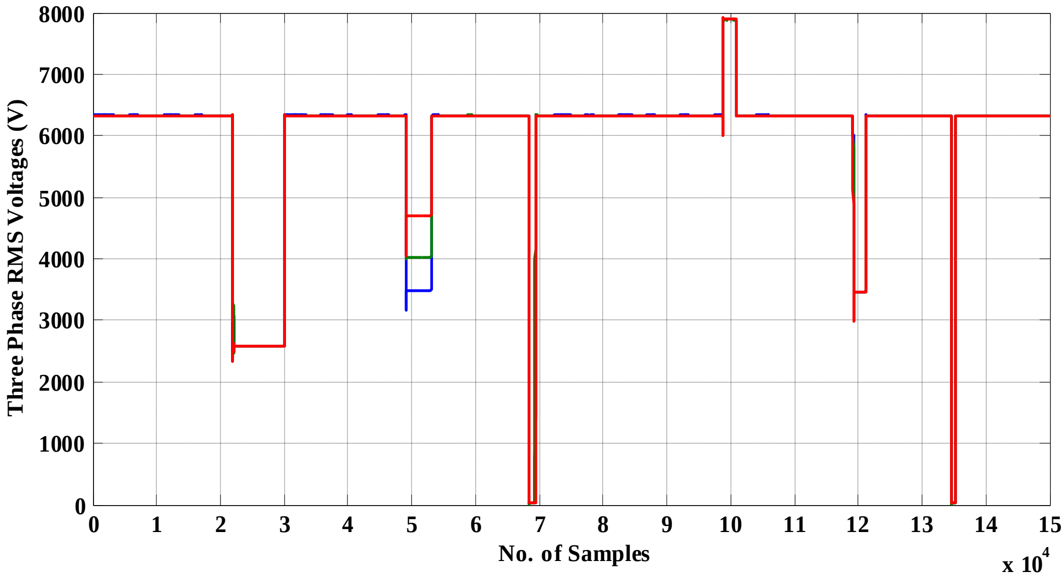

Fig. 2. Three Phase RMS voltages calculated at PCC

The logic checks whether the 3-phase RMS voltage samples are within the range of 0.9 p.u. to 1.1 p.u. and the samples which violate this condition are extracted for further classification. There are 17714 samples extracted from this logic which are given as inputs to the MATLAB program written for classifying & characterizing the power quality problems.

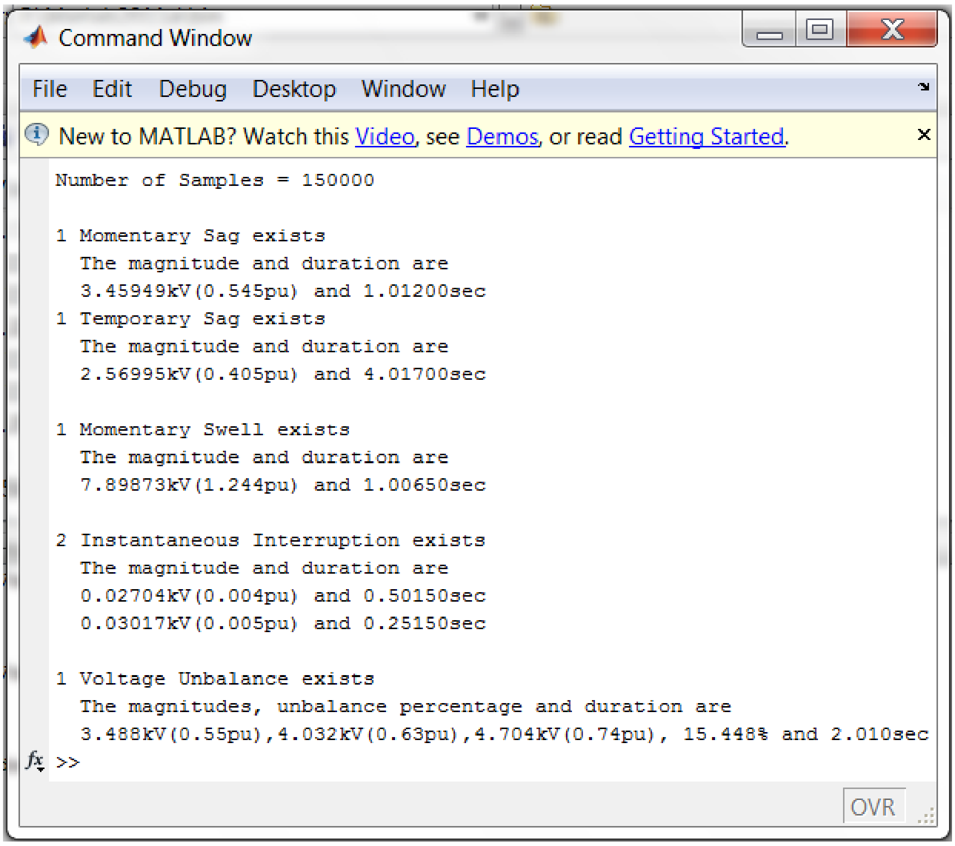

Fig. 3. Output from the actual voltage samples

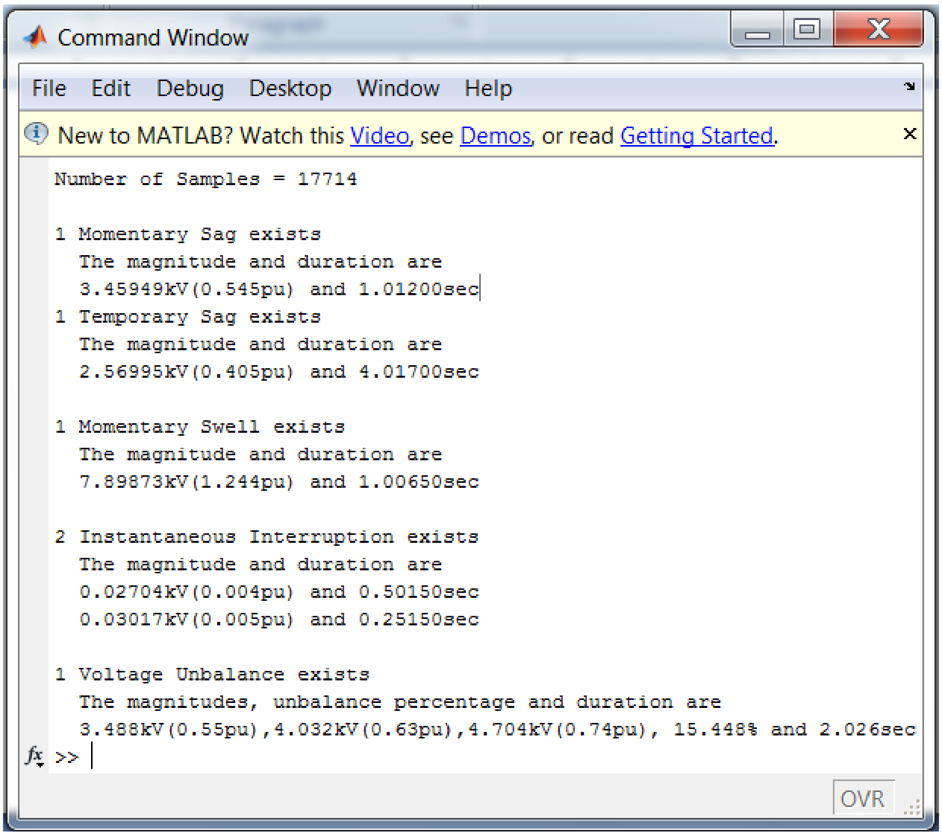

Fig. 4. Output from the extracted voltage samples

The program checks the extracted voltage samples for balanced or unbalanced conditions. If it is balanced case, the 3-phase RMS voltages will be same and this value is compared with the voltage ranges of sag, swell & interruption. If the voltage sample matches with any of these ranges, the magnitude of the voltage is noted and such samples are counted to obtain the duration of the disturbance. The time duration obtained is used to determine whether the problem occurred is of instantaneous, momentary, temporary or sustained type. Under unbalance conditions, the 3-phase RMS voltages will be different and the voltage unbalance percentage is calculated. If this value exceeds 2%, the 3-phase voltage magnitudes are noted along with unbalance percentage. Then the sample counting starts and continues till the unbalance condition is satisfied. If the same type of problem occurs for the next time, along with magnitudes & time period calculation, the count of occurrences is also incremented. This process continues till all the samples are completed.

The outputs of the program for the actual samples and for the extracted samples are shown in Fig. 3 and Fig. 4 respectively. Both the outputs obtained are same, but the output in Fig. 3 has taken all the samples of 150000 whereas the output shown in Fig. 4 is obtained from only 17714 samples. From this it is clear that the data to be handled by the program in first case is huge and takes much time for analysis whereas data to be handled by the program in second case is precise and takes very less time for the analysis. This is the advantage of using data extraction technique before giving the data to the classification program. The program output clearly indicates which type of problems has occurred and how many times with the indication of magnitudes and time durations. The program output demonstrates the effectiveness of the proposed algorithm in recognition, classification and characterisation of different categories of power quality problems considered in less time by making use of data extraction.

VI. CONCLUSION

This paper presents the data extraction from a huge amount of recorded data and a program for classification & characterization of power quality events. Sag, swell, interruption and unbalance conditions are applied to the MATLAB simulation model of a distribution system considered. Data samples in terms of 3-phase RMS voltages are measured and data extraction technique is used to reduce the number of samples for processing. From 150000 recorded samples, 17714 samples are extracted and are analysed using the algorithm written in MATLAB m-file. The algorithm identified the different types of power quality problems considered and presented the output in terms of type of problem, its magnitude, duration and number of occurrences of that problem. The classification program output shows the ability of the proposed algorithm in identifying, classifying and characterizing all the categories of considered power quality problems with an aid of reducing samples from the data extraction. This broader characterization of power quality events is intended to improve the estimation of load tolerance and reduce investments on sag, swell, unbalance and interruption mitigation.

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