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Online Identification and Classification of Different Power Quality Problems

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Abstract: Power quality has been the focus of considerable research in recent years because of the wide application of high-power electronic switchgears day by day. The main reason for having keen interest in the power quality lies in the huge economic value which directly associates with the power quality disturbances. Thus, it is essential to establish a monitoring system to detect power quality disturbance. In this paper, a simple approach to classify power quality problems based on C-Programming is presented. This approach obtains the instantaneous values of voltages and currents of the individual phases and computes THD, RMS, DC and IT-product values. The computed values are then given as inputs to the program which decides the type of power quality problem and outputs the digital value. The program is tested for various power quality problems by using MATLAB/SIMULINK. The simulation results are presented for the classification of sag, swell, unbalance, interruption, DC offset, harmonics and telephonic interference.

Keywords: Classification, Digital output, online detection, Power quality problems, Telephonic interference.

I. INTRODUCTION

In the recent years, the power quality has deteriorated significantly due to the increased use of non-linear and power electronic switching loads in the power system. The poor power quality is usually caused by the disturbances such as faults, interruptions, under voltages, over voltages, harmonic distortions etc. The poor quality of the power adversely affects the high sensitive loads like microprocessor based controllers, computers and leading to malfunctioning, short lifetime, instability etc. So, to improve the power quality, the electrical utilities should provide the real time monitoring systems which are capable of identifying different power quality disturbances and making appropriate decision in maintenance and switching. For this, instruments should collect huge amount of data such as measured currents, voltages and occurrence times [1]. From the data collected, online or offline analysis is needed to be carried out to classify the disturbances [2]. Thus, it is important to monitor the current and voltage waveforms and classify them for the study of power quality.

The methods which exist for the identification and classification of power quality disturbances are onerous as they are primarily based on the visual inspection of the waveforms. Due to the recent developments in the signal processing and the pattern recognition, many classification approaches have arrived. These are mainly based on Fourier Transform, S-Transform, discrete wavelet transform and multiresolution signal decomposition [3]-[7]. The Fourier Transform (FT) based techniques are suitable only for analyzing stationary signals and extracting spectrum components of the signals at specific frequencies. In the Wavelet Transform based approach, a mother wavelet is employed for finding the wavelet coefficients of the signal which affects the effectiveness in identifying the disturbance present in the signal. Use of all these techniques leads to some time lag which is same as that of the chosen window length. This time lag limits the use of these techniques for the online implementation.

The envelope of the signal can be estimated by various estimation methods such as the Kalman Filter (KF), the Least Absolute Value (LAV), the Simulated Annealing (SA) and the Adaptive Linear Neuron (ADALINE) [2], [8] & [9]. Although the KF is fairly accurate, it has a high mathematical burden which limits its use for on-line tracking. The LAV and SA algorithms require prior knowledge of the waveform, which is not feasible [2]. Although, the detection and identification of a disturbance using neural networks seemed to be appropriate but this requires a specific architecture for a specific type of disturbance.

One of the drawback of the neural network is it requires significant training for its operation. One well known disadvantage of Gradient Descent (GD) is that solution can get stuck in any local minimum and it can take much iteration to converge. Moreover, these researches did not concentrate on the telephonic interference caused by the power quality disturbances.

Hence, a simple method is developed for the identification and classification of various power quality problems including sag, swell, unbalance, interruption, DC offset harmonics and telephonic interference. The method is based on C-Programming which is simple and suitable for on-line implementation and presents the output in digital form. This online method can be used to trigger the control circuits to mitigate the power quality problems.

The paper is organized as follows—Section II describes the proposed classification algorithm for the identification and classification of power quality problems. Section III deals with the simulation to test the algorithm and the results are discussed in Section IV. Finally conclusion is given in Section V.

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II. CLASSIFICATION ALGORITHM

The following steps are implemented for the proposed classification algorithm:

1. Measure three phase instantaneous voltages (v_a, v_b, v_c) and currents (i_a, i_b, i_c) at the Point of Common Coupling (PCC).
2. Initialize the variables: V_{ref} (Reference voltage) to rated value of the voltage at PCC; Sag, Swell, Unbal (Unbalance), Intr (Interruption), THD (Total Harmonic Distortion), TI (Telephonic Interference) and DCoffset to zero.
3. Compute V_{arms}, V_{brms}, V_{crms} (RMS values of the three phase voltages), DC value, THD_v& IT product.
4. If DC value ≠ 0, set DCoffset to 1 & go to step 9.
5. If ($V_{arms} = V_{brms} = V_{crms}$), go to step 6 else set Unbal to 1 & go to step 9.
6. If ($0.1*V_{ref} \leq V_{arms} \leq 0.9*V_{ref}$), set Sag to 1 & go to step 9.
7. If ($1.1*V_{ref} \leq V_{arms} \leq 1.4*V_{ref}$), set Swell to 1 & go to step 9.
8. If ($V_{arms} < 0.1*V_{ref}$), set Intr to 1.
9. If ($THD_v > 5$), set THD to 1.
10. If (IT > 10,000), set TI to 1.
11. Display all the variables.

The variables Sag, Swell, Unbal, Intr, THD, TI, and DC offset gives the information about the type of power quality problem. Whenever any power quality disturbance occurs, the corresponding variable becomes 1, otherwise it remains as zero.

This algorithm is constructed based on the standard definitions and limits of power quality disturbances [10], [11]. It uses simple logic and is easily coded and executed using C-language. It gives the results in digital form of either 0 or 1. The proposed algorithm can be implemented online for the identification and classification of power quality problems.

III. SIMULATION CIRCUIT

The simulations are carried out for the classification of power quality disturbances by using MATLAB software. The disturbances include voltage sag, swell, unbalance, interruption, harmonics and dc offset. Fig. 1 shows the simulation circuit diagram which is used to test the classification algorithm proposed. The circuit consists of a 3-phase AC voltage source of 25kV supplying power to the load of 10kVA. The voltage sag of 0.765 p.u. is created by a 3-phase to ground fault with fault impedance from 1s to 2s. The voltage swell of 1.2 p.u. is created from 3s to 4s by switching on a capacitive bank. The voltage unbalance of 10.68% is created by a 3-phase unbalance fault from 5s to 6s.

The interruption is introduced by creating a 3-phase to ground fault from 7s to 8s. The DC offset of 4166V is created by inserting a DC voltage source in series with the source from 9s to 10s. To create harmonics, a diode bridge rectifier feeding a DC motor is used which will be present throughout the duration considered.

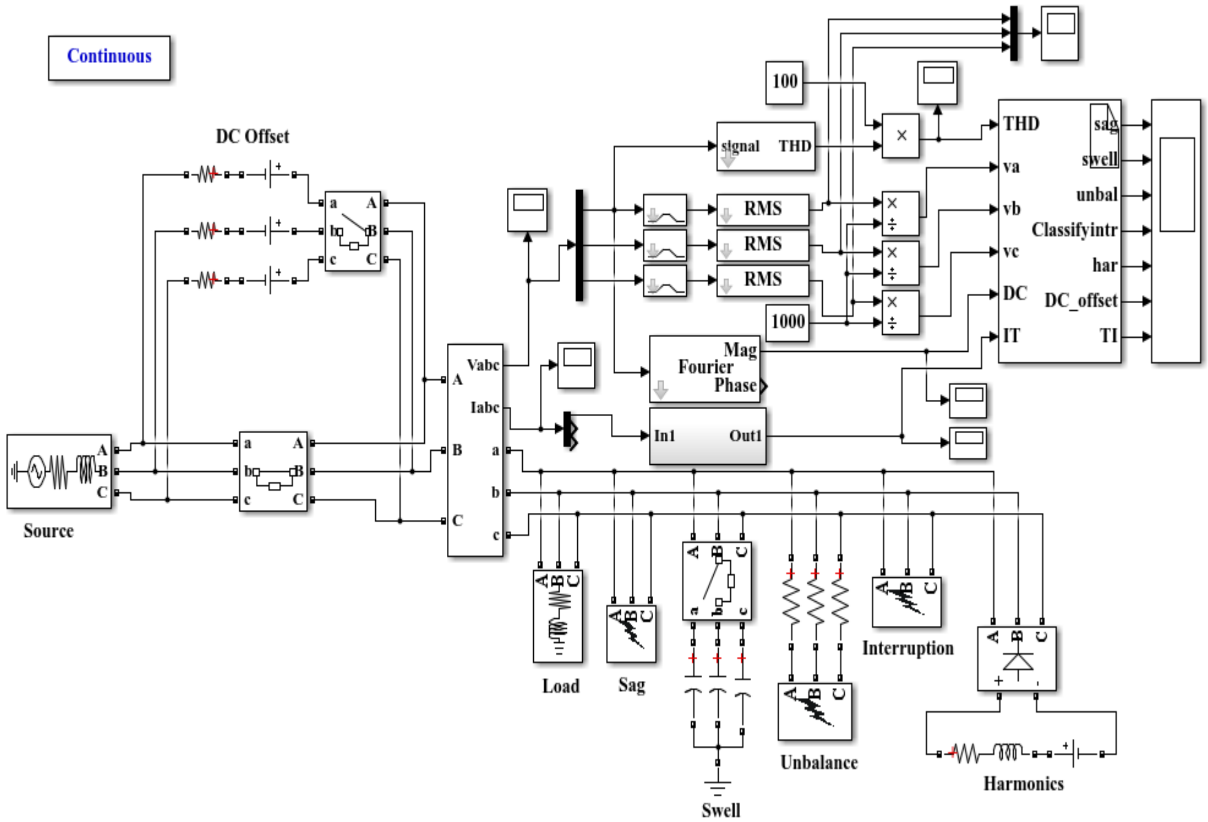

Fig.1. Simulation circuit diagram to test the classification algorithm

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The 3-phase instantaneous voltages and currents are measured at the load point. The measured voltage signals are filtered and 3-phase RMS quantities are obtained by taking the values for each half cycle for more accuracy [12] using (1).

$$V_{rms}(t) = \sqrt{\frac{2}{T}\int_{t-\frac{T}{2}}^{t} f(t)^2 dt} \qquad (1)$$

'T' is the time period of the voltage signal which is 0.02 s for 50 Hz frequency. As the RMS values are calculated continuously, a half cycle of simulation has to be completed before the output gives the correct value. For the first half cycle of simulation, the output is held to the RMS value of the specified initial input. DC value and THD are computed from the measured instantaneous voltage values using (2) and (3) respectively.

$$V_{DC}(t) = \frac{1}{T}\int_{t-T}^{t} f(t)dt \qquad (2)$$

$$THD = \frac{\sqrt{V_2^2+V_3^2+V_4^2+\cdots V_n^2}}{V_1} \qquad (3)$$

V_1 is the fundamental voltage. V_2, V_3, V_4...V_n are the 2nd, 3rd, 4th….nth order harmonic voltages.

A subsystem is modeled to calculate IT product from the instantaneous values of current. Fourier analysis is carried out on the current signal to obtain the harmonic components. These components are multiplied with the corresponding weighing factors [11] of harmonic frequency. IT product is computed using (4).

$$I.T = \sqrt{\sum_{h=1}^{\infty}(I_h . W_h)^2} \qquad (4)$$

Where, 'h' is the harmonic order, I_h is RMS harmonic current and W_h is the telephone influence factor weight at 'h' harmonic frequency.

The 3-phase RMS values of voltages, DC value, THD and IT product are given as inputs to the classification algorithm written in the S-function builder to classify the power quality problems. The algorithm analyses the inputs, checks for various conditions and specifies the type of the power quality problem by making the corresponding output signal to high.

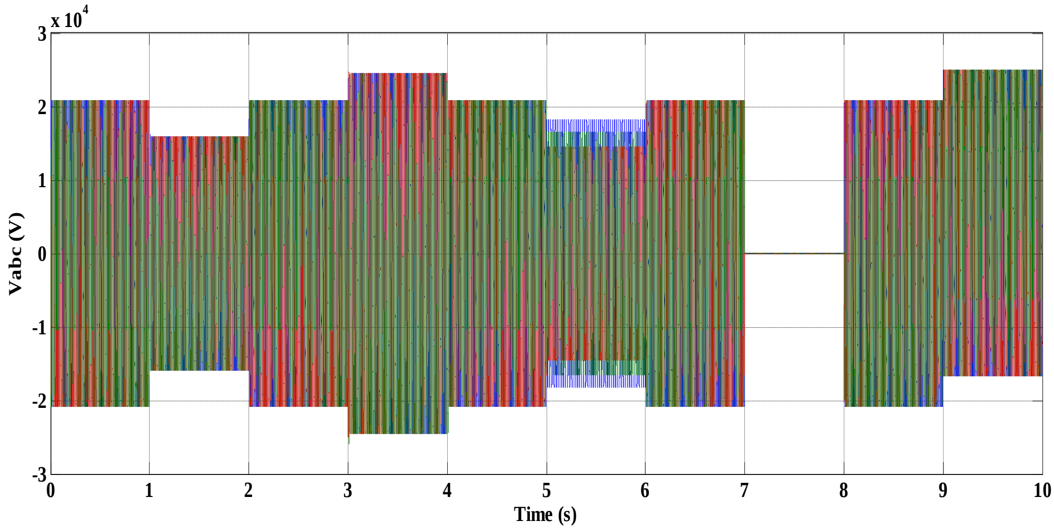

Fig.2. Three phase instantaneous voltages.

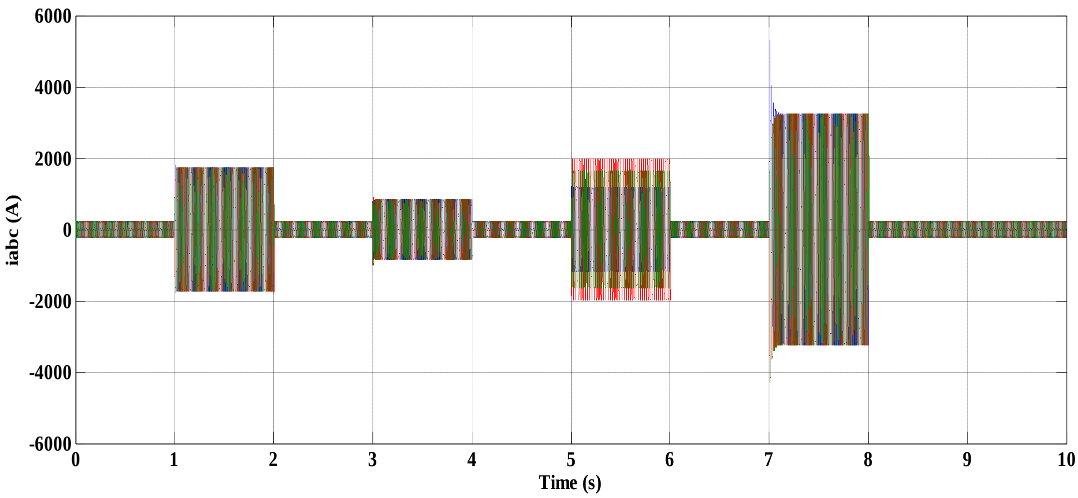

Fig.3. Three phase instantaneous currents.

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IV. SIMULATION RESULTS

The circuit in Fig. 1 is simulated for different power quality problems like sag, swell, unbalance, interruption, harmonics and DC offset. The three phase instantaneous voltages are shown in Fig. 2. The voltage envelope shows the deviations in the voltages due to the different power quality problems occurring. Fig. 3 shows the three phase instantaneous currents. It can be seen that the currents are high during the periods of sag, swell, unbalance and interruption. The three phase RMS voltages are shown in Fig. 4. From the figure, it is clear that there is voltage sag during 1s to 2s, voltage swell during 3s to 4s, unbalance during 5s to 6s and interruption during 7s to 8s. These voltage deviations will affect the load connected and results in failure/ malfunction of the equipment, reducing life and loss of production. Fig. 4 also indicates voltage rise during 9s to 10s due to DC offset. To identify this, RMS values are not enough and hence DC value is computed.

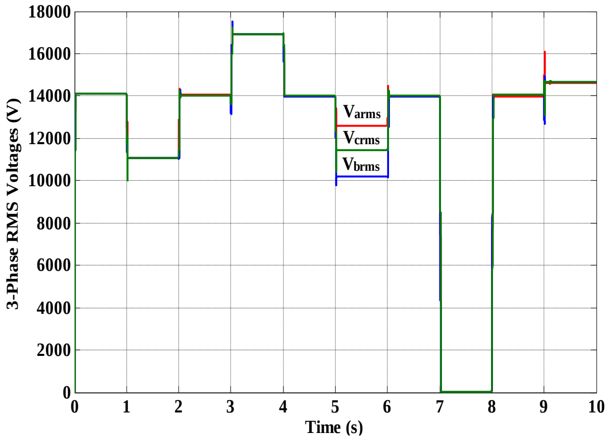

Fig.4. Three phase RMS voltages

The DC value of the voltage waveform is indicated in Fig. 5 which shows that there is DC voltage (4166V) existing in the waveform during 9s to 10s. This DC value will lead to the overheating, saturation of the transformers, ground fault current and nuisance tripping.

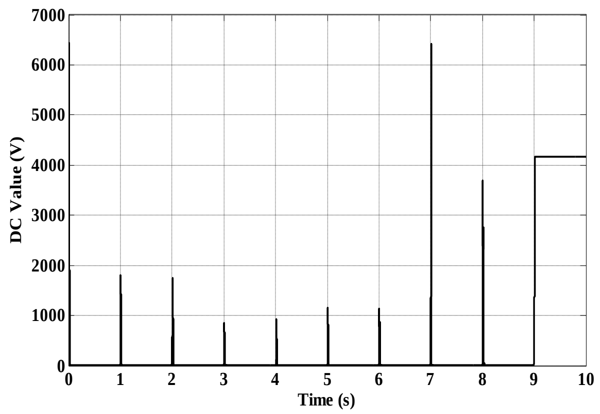

Fig. 5. DC Value of the voltage waveform.

The Total Harmonic Distortion of the voltage waveform is indicated in Fig. 6 which shows that its value exceeds the limit of 5% during the periods of 0 to 1s, 2s to 3s, 4s to 5s, 6s to 7s and 8s to 10s. In these durations, the effect of harmonics will be more and lead to overheating of neutral conductors, transformers, other electrical equipment and also causes circuit breakers tripping & loss of synchronization.

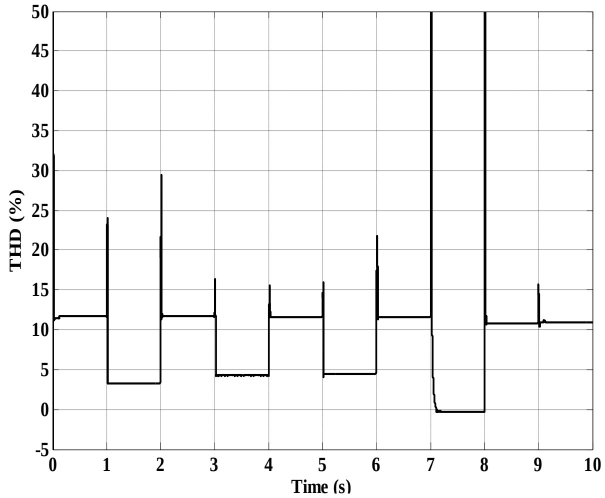

Fig. 6.Total Harmonic Distortion of the voltage waveform.

The IT product of the current waveform is indicated in Fig. 7 which shows that its value exceeds the limit of 10,000 for the duration considered except in the periods of 1s to 2s and 7s to 8s. In all the durations where IT product exceeds its limit, there will be interference to the telephonic lines. From Fig. 6 and 7, it is observed that even though THD is within the limit of 5% during 3s to 4s and 5s to 6s, the IT product exceeds the limit of 10,000. This shows the necessity of calculating IT product to identify the telephonic interference even though THD is known.

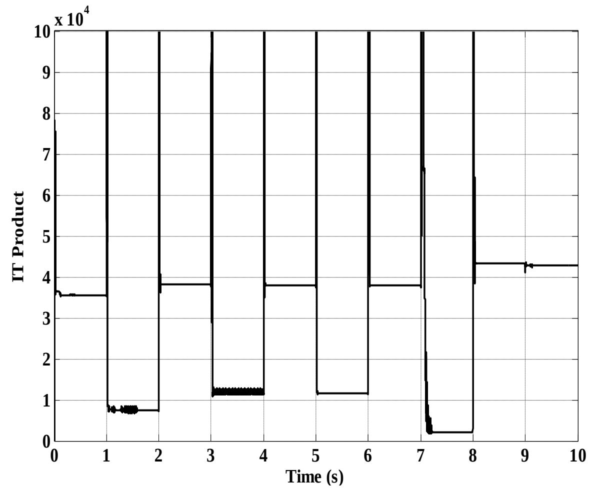

Fig.7. IT product of the current waveform.

Fig. 8 shows the simulated output signals of the classification algorithm after being subjected to the different power quality problems. The signals Sag, Swell, Unbalance, Interruption, Harmonics, DC Offset and Telephonic Interference goes high whenever the corresponding power quality problem occurs. The simulation results demonstrate the effectiveness of the proposed algorithm in recognition and classification of different power quality problems considered.

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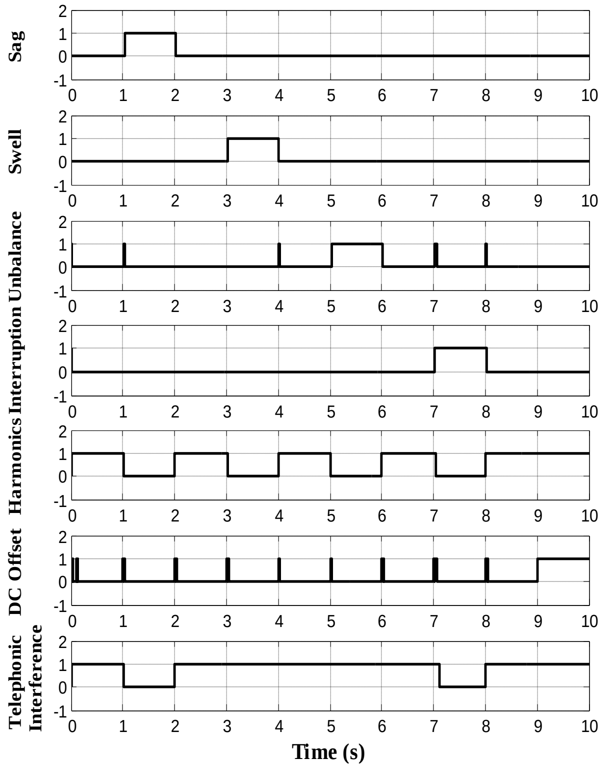

Fig.8. Output signals of the classification algorithm.

V. CONCLUSION

The paper has presented a simple approach for the identification and classification of power quality problems. The C-language based classification algorithm is considered for six different power quality disturbances such as Voltage Sag, Swell, Unbalance, Interruption, Harmonics and DC offset which is tested using MATLAB simulation. The simulation results show the ability of the proposed algorithm to identify and classify the power quality problems considered. The algorithm also calculates IT product to identify the telephonic interference. As the method proposed can be implemented online and presents the output in digital form, it can be used to trigger the control circuits to mitigate the power quality problem.

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BIOGRAPHIES

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