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A Non-Linear Signal Technique for PQ Analysis in Power System

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A B S T R A C T

Micro grids are very attractive for electrical power generation or power consumption owing to increased reliability. Implementing protection against various short-circuit problems is a significant task, a micro grid can use many different sources of generation, including solar PV and wind energy, it makes them a secure option when making an investment in renewable energy system. This project aims to proposes a simple model to estimation of apparent resistance per-phase of a three-phase or a single-phase ac power. In this the micro grid model is based on renewable energies like wind and solar distributed generations and utility. In order to protect the distribution lines that are part of the microgrid system, a protection strategy will be developed, with a goal to compare the estimated target indices with the actual ones. Any reasonable discrepancy between the two indices therefore indicates the development of fault along that line Then fault has been evaluated. then, the fault is looked at for a variety of case studies.

Keywords: Micro grids, PV, Wind energy, Renewable energy, Fault protection

1. Introduction

Power Quality (PQ) is defined as the bus voltage must be measured, analysed, and improved to maintain a sinusoidal waveform at the rated voltage and frequency.Poor-quality electricity is risky and expensive for both the utility and the consumer.A lot of attention must be paid to the quality of the power being delivered to the loads. The effectiveness and cost of a power system can be significantly impacted by power quality. Therefore, it is crucial to ensure that the power being consumed by the system is of the proper quality and that the system can operate with the power given to it. Since consumers are now very conscious of power quality, several governments have revised their policies to force electric utilities for making sure the power quality according to the designed standards. Unpredictable occurrences, the electric utility, the consumer, and the manufacturer are the primary causes of disturbances and power quality issues. Poor power quality has negative effects on both the utility and the customer. Some of the main implications of poor power quality are life time equipment is reduced because of overheating and noise, some important data may loss due to power loss, if there are poor power quality costs of power system has highly increased, because of power quality issues consumer loads are badly affected etc.

The methods which are commonly used for the power quality in power systems are Wavelet Transform (WT), Stockwell Transform (ST) and Hilbert-Huang Transform (HHT) and their hybrids. The PQ disturbance signals are subjected to all of these transforms in order to extract time frequency signatures. This method only works with stationary signals. The methods which are used for power quality monitoring are modern power plants use in-plant power monitors, smart relays, voltage recorders, digital fault recorders, and specialized power quality equipment to monitor their power. When a fault occurs, a digital fault recorder starts recording the voltage and current waveforms that led to the issue

In this paper, a Continuous Wavelet Transform (CWT) algorithm has been used. It uses the inner products to measure a similarity between a signal and an analysing function. Apart from the introduction in the Section 1, Section 2 describes the Power Quality distribution in power system. In Section 3 describes the signal process algorithm which means that CWT. In Section 4 describes that analysis of synthetic data. In Section 5 discuss about the analysis of practical data. In Section 6 about performance analysis.

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2. PQ Disturbances in Power System

Power quality is any abnormal behaviour on a power system arising in the form of voltage or current, which affects the normal operation of electrical or electronic equipment. Grounding, neutral to ground voltages, ground loops, ground current, and other ground-related problems are all related to poor power quality. In this PQ disturbance detection has four strategies to classified the signal. Those are SSD (Sparse Signal Decomposition), event detection, PQ feature extraction and classification. The detail signal containing transients and waveform distortions (such as harmonics, inter harmonics, spike/impulse, notching, and noise and the other sinusoidal PQ disturbances such as sag, swell, flicker, interruptions and frequency variations. Finally, to compared the extracted PQ indices with their typical parameters for detection and classification of different types of PQ disturbances.

2.1. Sag

A voltage sag or voltage dip is a short duration reduction in the voltage of an electric power distribution system.
here are several factors which cause voltage sag to happen:

1. Starting an electric motor can cause voltage sag because electric motors consume more current when they are starting than when they are operating at rated speed.
2. There will be voltage sag following a line-to-ground fault until the protection switch gear engages.
3. Lightning strikes or objects falling from the sky can produce line-to-ground faults in power lines, which can lead to voltage sags

2.2. Swell

A voltage swell is an increase in the RMS voltage above the nominal voltage or a sliding reference voltage. The increase lasts from half a cycle to several seconds.
There are several factors which cause voltage sag to happen:

1. Deenergizing a massive load can also result in voltage surges.
2. It may result in the breakdown of parts on the equipment's power supplies, however the damage may be gradual and cumulative. Due to overheating, it may eventually cause equipment shutdown and result in control issues and hardware failure. Voltage swell can also harm delicate equipment like electronics and other devices.

2.3. Flicker

It is defined as the short-term voltage fluctuations in the power supply system. This can cause lamps to the flicker, as the brightness is proportional to the applied voltage.

2.4. Harmonics

The main representation of power quality is the harmonic distortion, which represents the deviation between the ideal sinusoidal waveform the network voltage or the load current should have, and what really it is. There are different types of harmonics like 1^{st} harmonic, 3^{rd} harmonic, 5^{th} harmonic…... and so on.

2.5. Transients

- Transients are abrupt, significant changes in the voltage or current levels relative to the usual.
- There are two types of transients. They are impulsive and oscillatory.
- Impulsive means a unidirectional current or voltage that experiences a rapid, low-power frequency change in steady state.
- Oscillatory means a bidirectional current or voltage that experiences a rapid, low-power frequency change in steady state.

2.6. Voltage Fluctuations

- Voltage fluctuations are defined as an abrupt change in the actual and reactive power drawn by a load cause the voltage envelope to repeatedly or randomly vary. Voltage fluctuations features are influenced by the kind, size, and power system capacity of the load.
- For voltage fluctuation the waveform varies the magnitude due to the fluctuating nature or intermittent operation of connected loads

3. Signal Process Algorithm

In this project, a continuous wavelet transform algorithm has been applied.

A wavelet is a wave like oscillation that is localized in time. Wavelets are divided into two basic properties they are scale and location. Scale describes the how a wavelet is stretched or squished and it is also related to frequency. Location describes where the wavelet is positioned in time.

$$\text{Wavelet Transform: } -(x-b)e^{-\frac{(x-b)^2/(2a)^2}{\sqrt{2\pi a^3}}}$$

Wavelet transforms are categorized into two types they are Continuous and Discrete. Continuous Wavelet Transform (CWT) uses inner products to measure a similarity between a signal and an analysing function. Every wavelet that can be used in CWT is used over an infinite number of scales and places. While in Discrete Wavelet Transform (DWT) uses a finite set of wavelets that is defined at a particular set of scales and locations.

In mathematically, the CWT is a tool which provides the overall representation of the signal by continuously varying the wavelet translation and scale parameter according to the following equation:

$$WT_{u,a} = (s, \psi_{u,a}) = \int_{-\infty}^{\infty} s(t)\psi *_{u,a} (t)\, dt$$

Were

$$\psi_{u,a} = \frac{1}{\sqrt{a}}\psi\frac{(t-u)}{a}$$

Where WT $_{u,\,a}$ is the resulting for the wavelet coefficients. $\psi_{u,\,a}$ is the continuous wavelet in that u is the shift factor and a is the scale factor of the wavelet.The shift factor can be any real value, whereas the scale factor for the continuous-time signal must be a positive real number.You can utilize the obtained wavelet coefficients to reconstruct the original signal if the continuous wavelet $\psi_{u,\,a}$ satisfies the admissibility criterion.

The mother wavelet is a continuous function that exists in both the time domain and the frequency domain. The action of a complex conjugate is shown by the overline. The mother wavelet's primary job is to act as a source function for the daughter wavelets, which are just scaled and translated counterparts of the mother wavelet. The first inverse continuous wavelet transform can be used to retrieve the original signal. The next section describes about the analysis on synthetic data.

4. Analysis on Synthetic Data

These are some of the results getting from the PQ disturbances. Some of them are voltage sag, voltage swell, notch, flicker, harmonics…... etc. Here are some of the graphs for PQ disturbances.

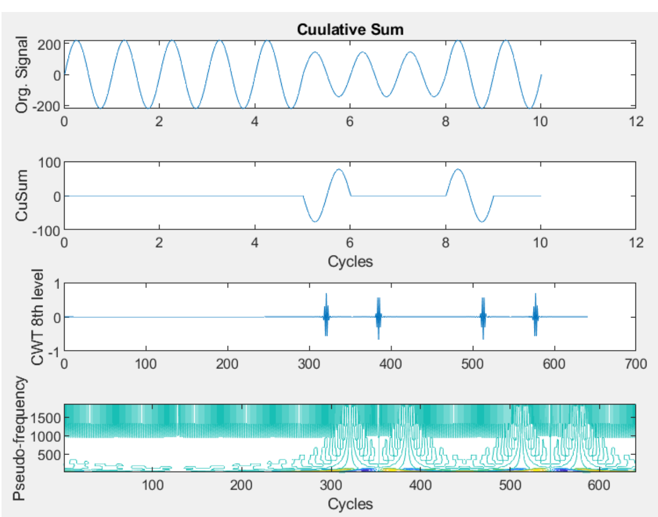

Fig. 1–Sag

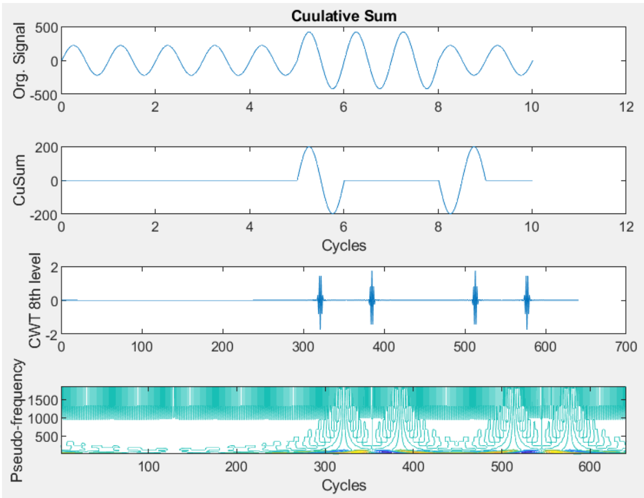

Fig. 2 – Swell

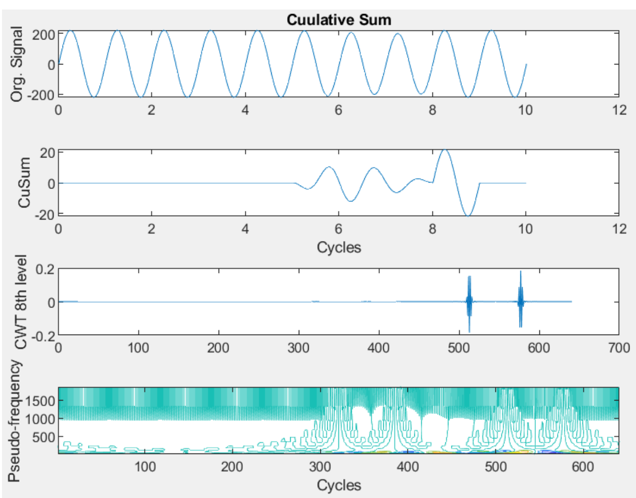

Fig. 3 – Flicker

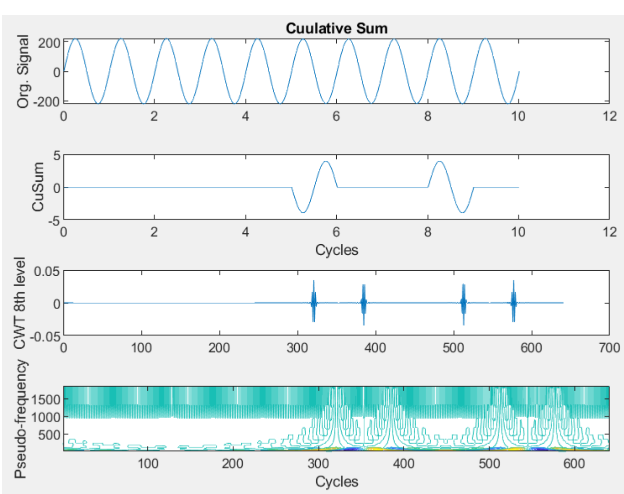

Fig. 4 – Interruption

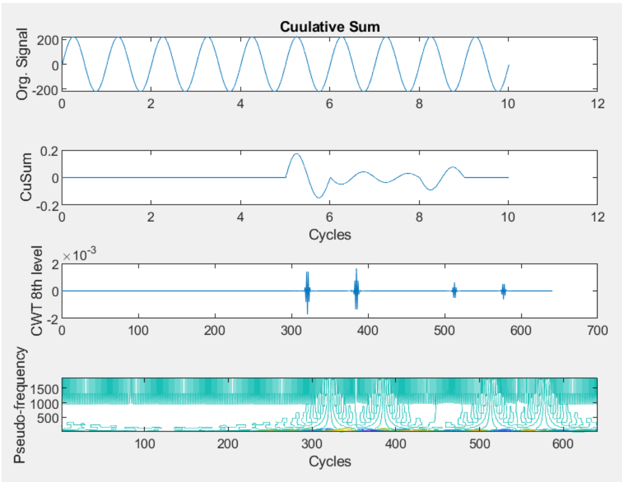

Fig. 5 – Transients

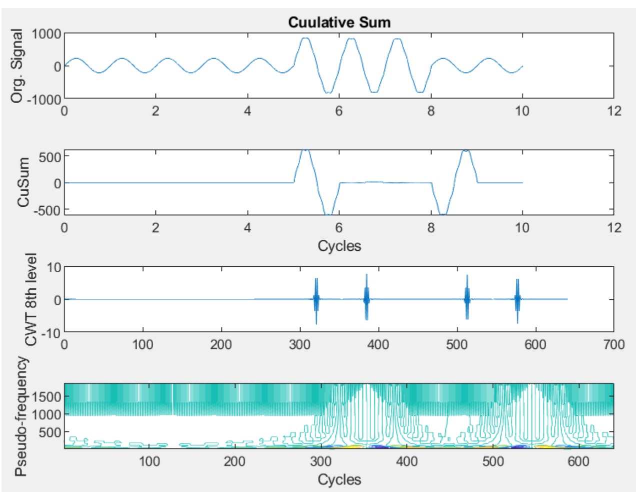

Fig. 6 – Flicker + Swell

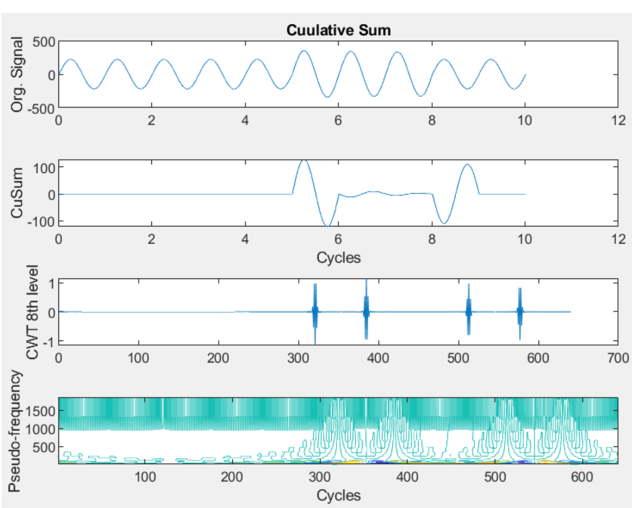

Fig. 7 – Flicker + Sag

5. Analysis for Practical Data

5.1. Description

The single line diagram of the proposed system as shown in the figure. The system's fundamental characteristics taken from the IEEE Standard's with some modifications. The model consists of 154kV grid, which is connected to the rest of the network which is having 154kV/22.9kV 47MVA transformer 1 and 22.9kV line. There are three phase RL branches in each of the five loads L1, L2, L3, L4 and L5. The test model consists of two distributed generating units. They are D.G.-1 and D.G.-2. The D.G.-1 and D.G.-2 is a doubly fed induction generators based on the solar farms, which could include sufficient energy storage. The solar farm is made up of a voltage source converter (VSC), which serves as the channel for communication between the source and the power system. A constant PQ control method is used to control the inverters placed in the solar farm. All the loads and transmission lines are present on the 22.9kV line of the model. The bus B4 which is considered as the PCC (Point of Common Coupling). At last, after the bus B4 it is having only DG units and loads. This model is capable to operate in an islanding mode after the disconnection from the main grid. The next section describes about the performance analysis.

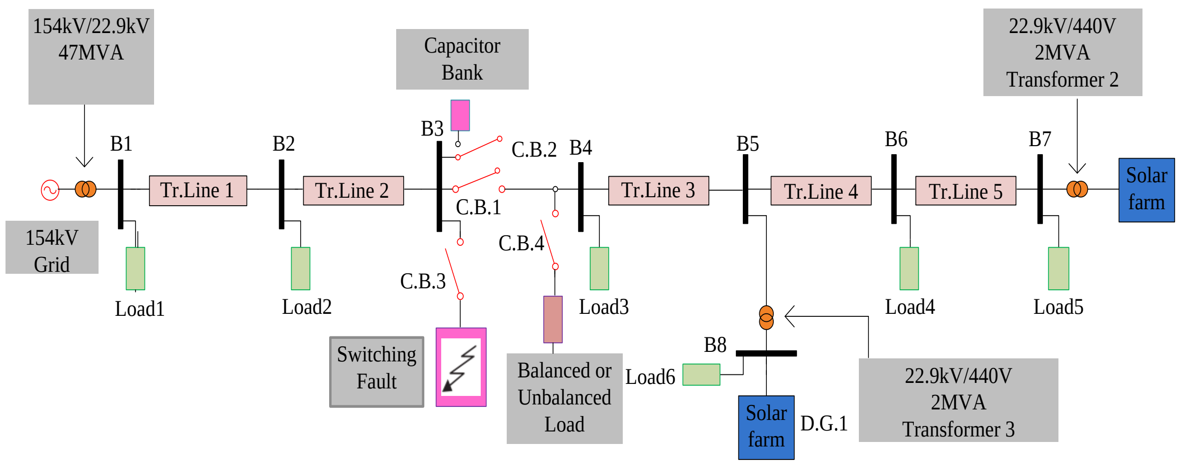

Fig. 8–Single line diagram of the 7-bus distributed generation system

5.2. Indices of the system

Energy of the signal (x_1): For a signal Y(t), with samples L_s where, s=1, 23, ……., S and it is defined as

Energy (x_1) = $\sum_{s=1}^{S} L^2_s$

Entropy of the signal($x2$): Entropy is simply the average amount of the information from the event

Entropy (x_2) =$\sum_{s=1}^{S}$ $L_s \log_h (L_s)$

where M = total sample number

Maximum amplitude of signal(x3): It is defined as the maximum value of the output of the STMHT and MSMGF over the entire input signal.

Standard Deviation (x_4): It is defined as an attribute that enumerates the amount of deviation in a set of data values. Mathematically

Standard deviation (x_5) = $\sqrt{\frac{1}{S}\sum_{s=1}^{S}(Ls-\hat{L}_{\beta}})^2$

Were

$$\widehat{Ls}_{\beta} = \sum_{s=1}^{S} Ls$$

And the $\hat{L}_{\beta}$ is defined as the mean of the data values of L(S).

5.3. Test System

Event 1 (E1): Load ON
Event 2 (E2): Load OFF
Event 3 (E3): Capacitor switching
Event 4 (E4): Line 1 to Line 2
Event 5 (E5): Line 2 to Line 3
Event 6 (E6): Line 1 to Line 3
Event 7 (E7): Line 1 to Line 2 to Ground
Event 8 (E8): Line 3 to Line 3 to Ground
Event 9 (E9): Line 1 to Line 3 to Ground
Event 10 (E10): Line 1 to Ground
Event 11 (E11): Line 2 to Ground
Event 12 (E12): Line 3 to Ground
Event 13 (E13): Line 1 to Line 2 to line 3 Ground
Event 14 (E14): Line 1 to Line 2 to line 3
Event 15 (E15): Islanding

a) Load ON:

In this Event1-load ON when suddenly load increases, then load current will increases and the voltage drop is in the transmission lines will also increases and that voltage and current only delivered to the system. In the system the graphs of voltage and currents graphs are like the figure9 this also called voltage sag.

b) Load OFF:

In this Event1-load ON when suddenly load increases, then load current will increases and the voltage drop is in the transmission lines will also increases and that voltage and current only delivered to the system. In the system the graphs of voltage and currents graphs are like the figure10 this also called voltage swell.

c) Capacitor Switching:

The capacitor switching is such as disconnecting a line or a cable or a bank of capacitor poses serious problems in power systems in terms of abnormally high voltages across the circuit breaker contacts. Under this situation the currents lead the voltage by about 90°.

This capacitor switching is considered to be a normal event on a utility system, and the transients associated with these operations are generally not a problem for utility equipment. However, the transients can be magnified in a customer facility – if the customer has low-voltage, power-factor correction capacitors. In the system the graphs of voltage and currents graphs are like the figure11.

d) Line to Line:

This types of line-to-line faults are occurs when one phase line (A, B and C) is shorted to another phase line. In this line-to-line faults are three types those are:

→ Line A to line B
→ Line B to line C
→ Line C to line A

e) Line to Ground:

This line to ground type faults are occurs when one phase line (A, B and C) is shorted to ground. In this line-to-line faults are three types those are:

→ Line A to Ground
→ Line B to Ground
→ Line C to Ground

f) Line to Line to Ground:

This line to ground type faults are occurs when one phase line (A, B and C) is shorted to anther line to ground. In this line-to-line faults are three types those are:

→ Line A to line B to Ground
→ Line B to line C to Ground
→ Line C to line A to Ground

These three types of faults (**line to line, line to ground and line to line to ground**) are called as unsymmetrical faults. Line to ground fault (L-G) is most common fault and 65-70 percent of faults are of this type.
It causes the conductor to contact earth or ground. 15 to 20 percent of faults are double line to ground and causes the two conductors to contact ground. Line to line faults occur when two conductors contact each other mainly while swinging of lines due to winds and 5- 10 percent of the faults are of this type.

These are also called unbalanced faults since their occurrence causes unbalance in the system. Unbalance of the system means that that impedance values are different in each phase causing unbalance current to flow in the phases. These are more difficult to analyze and are carried by per phase basis similar to three phase balanced faults. In the system the graphs of voltage and currents graphs are like the figure12 and 13.

g) Line to Line-to-line Ground:

These types of faults are occurring due to breakdown of insulation between all the three phases. these are very severe faults and occur infrequently in the power systems.

h) Line to Line to line:

These types of faults are occurring due to breakdown of insulation between all the three phases as well as to the ground. these are very severe faults and occur infrequently in the power systems.
These two types of faults (**Line to Line-to-line Ground and Line to Line to line**) are called symmetrical faults. These are Only 2-5 percent of system faults are symmetrical faults. If these faults occur, system remains balanced but results in severe damage to the electrical power system equipment. Above figure shows two types of three phase symmetrical faults. Analysis of these faults is easy and usually carried by per phase basis. Three phase fault analysis or information is required for selecting set-phase relays, rupturing capacity of the circuit breakers and rating of the protective switchgear. In the system the graphs of voltage and currents graphs are like the figure14.

i) Islanding:

Islanding is a defence mechanism for the power system in which a part of the system is islanded from a distributed grid so that this subpart could survive in isolated from rest of grid and continuity of supply to the essential load in an area. In the system the graphs of voltage and currents graphs are like the figure15.

5.4. Indices of the system

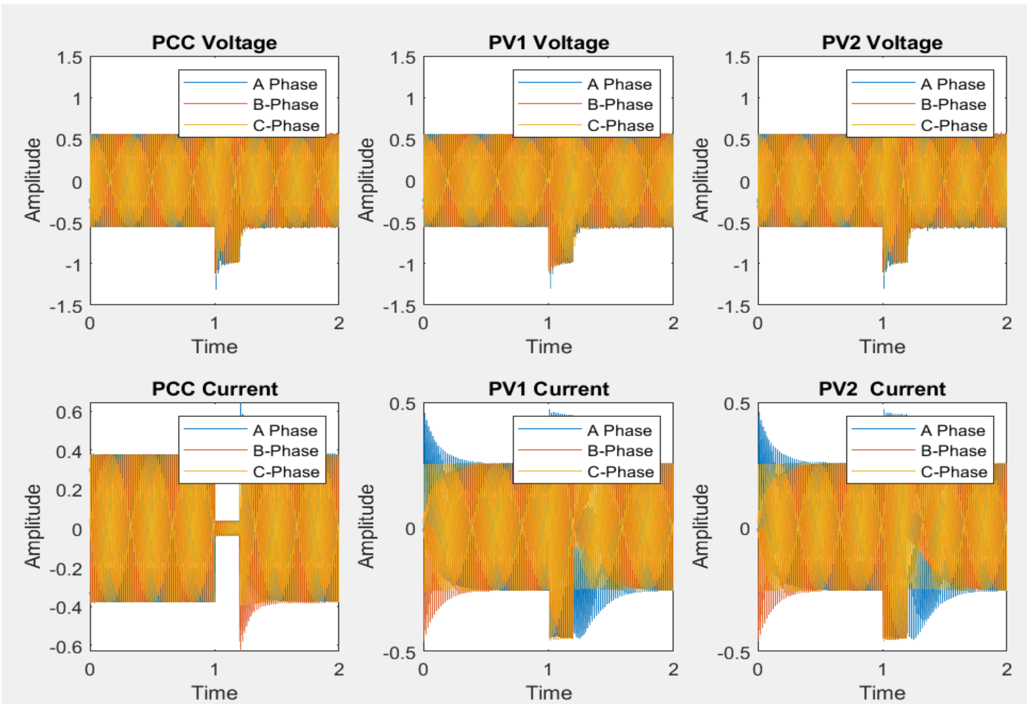

Fig. 9 – Voltage and currents for load ON event

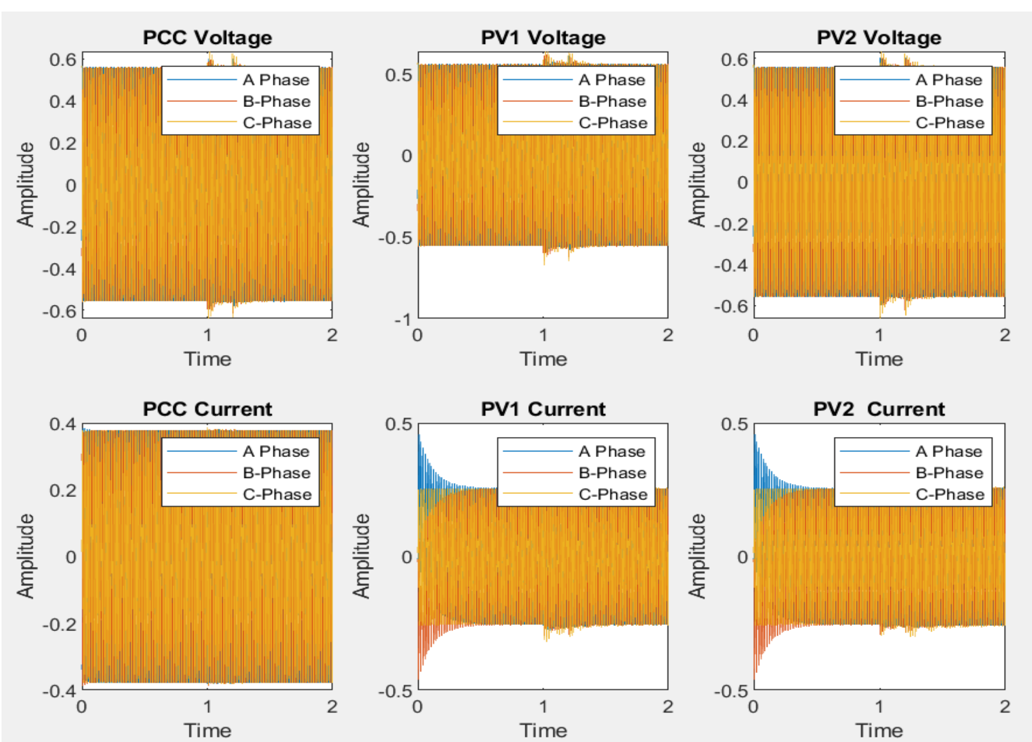

Fig. 10– Voltage and currents for load OFF event

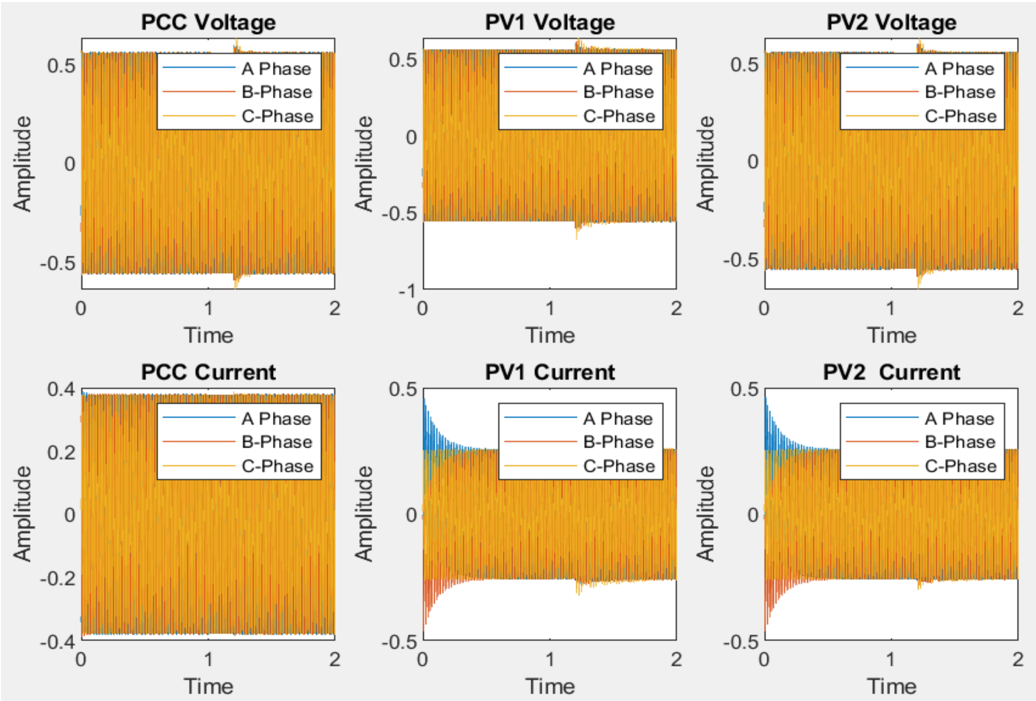

Fig. 11 – Voltage and currents for capacitor switching event

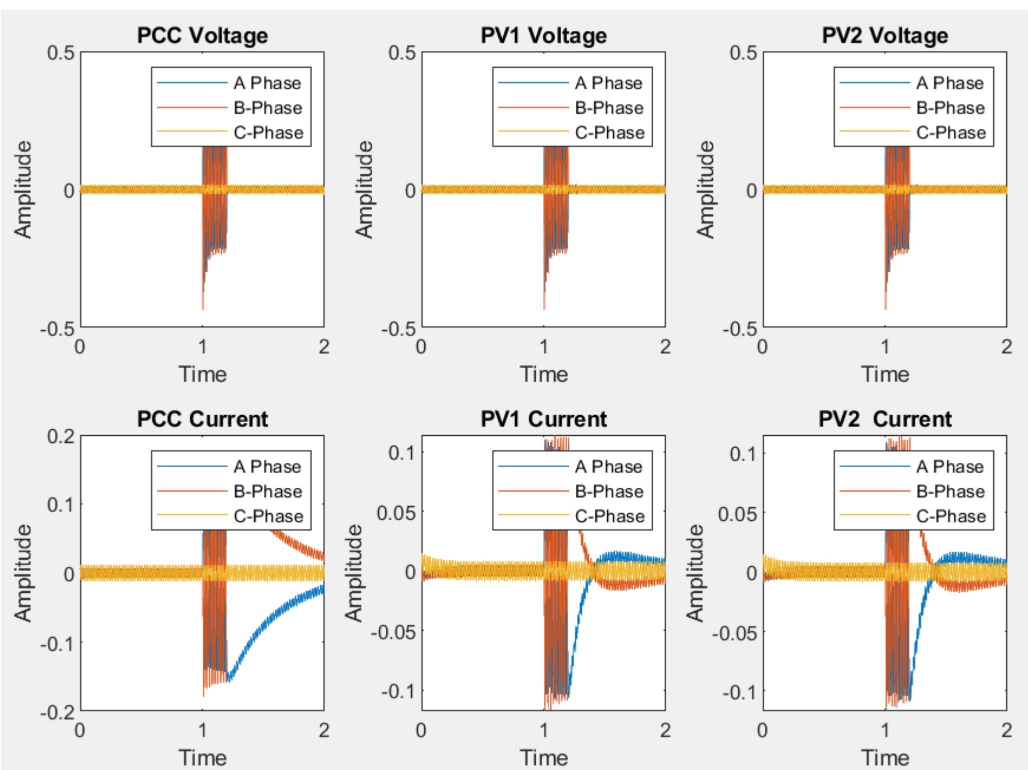

Fig. 12 – Voltage and currents for unsymmetrical event1

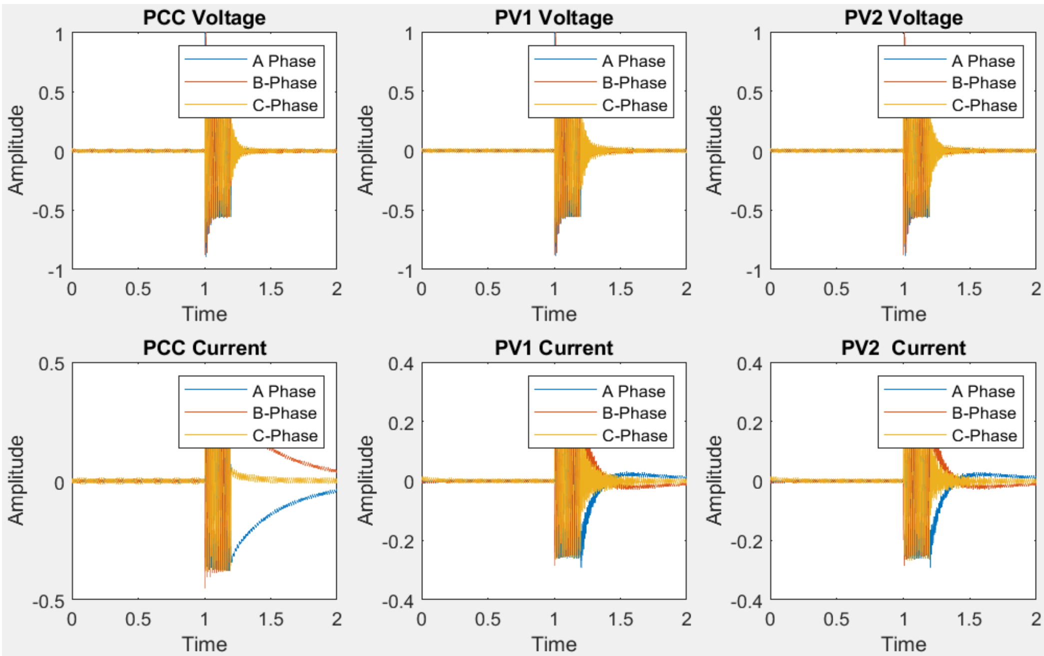

Fig. 13 – Voltage and currents for unsymmetrical event2

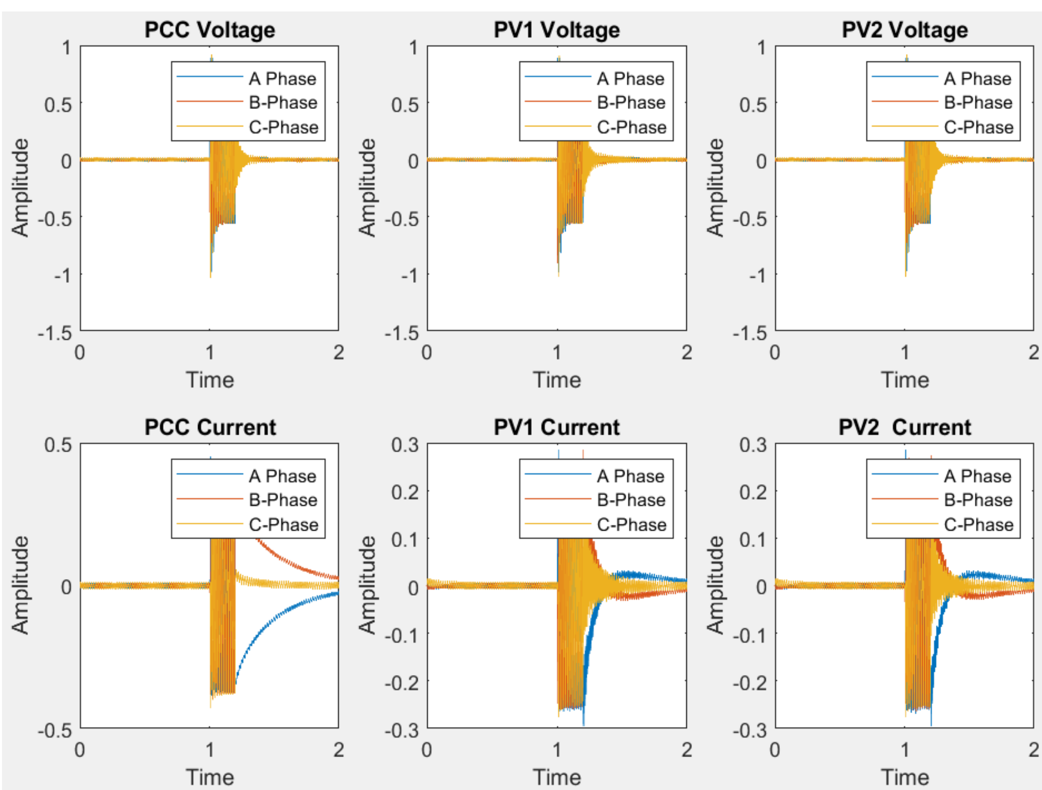

Fig. 14 – Voltage and currents for symmetrical event

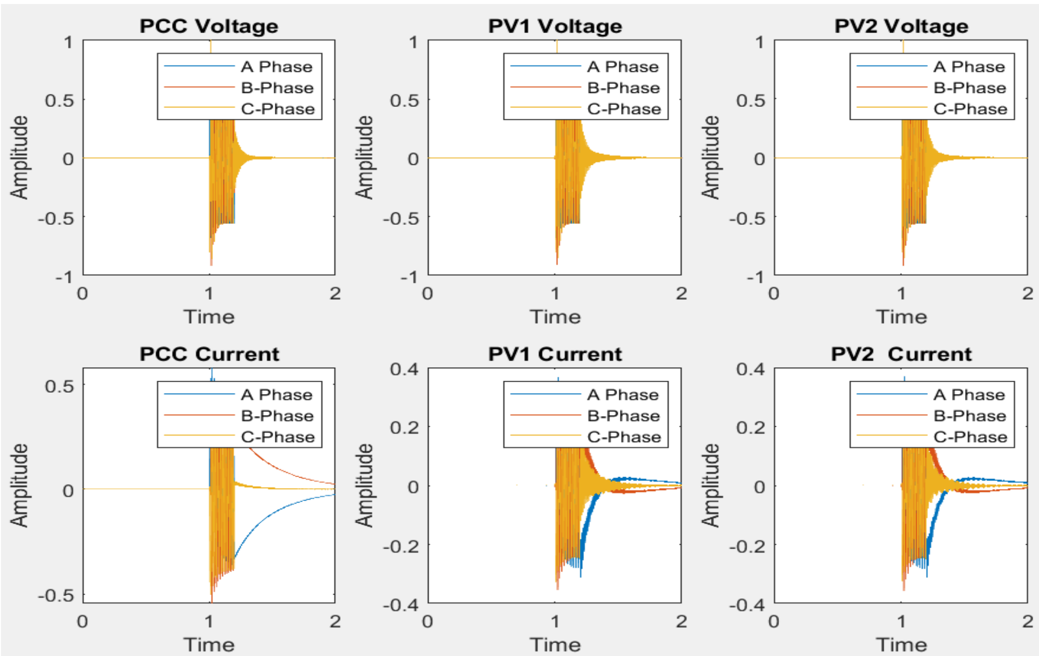

Fig. 15 – Voltage and currents for islanding event

6. Results

The below figures are categorized into three different faults. In that the first range of fault is in phases like line to ground and line to line to ground, the second peak fault is capacitor switching and the third fault is islanding mode.

From the below graphs the success percentage is 73.8516.

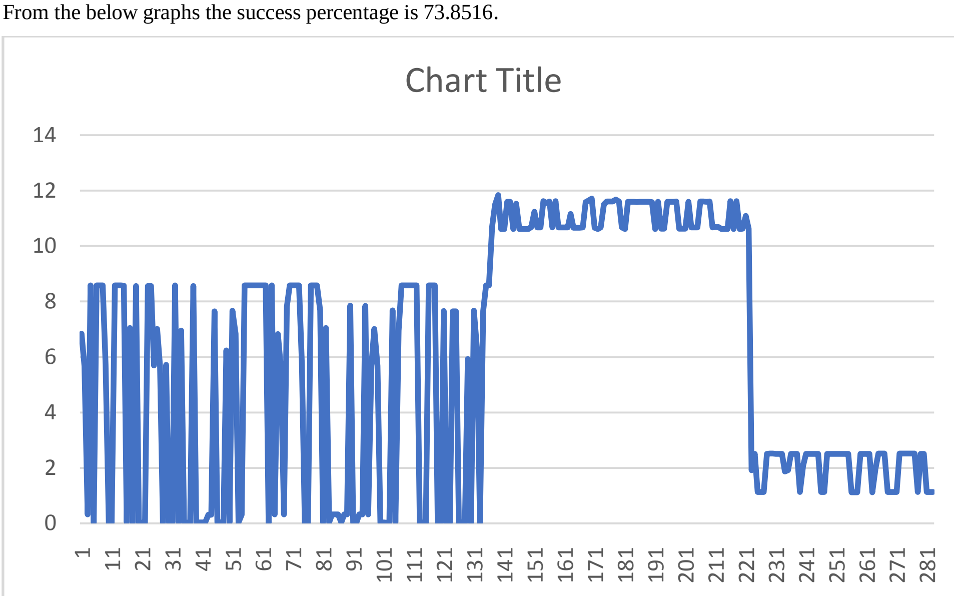

Fig. 16 – Entropy

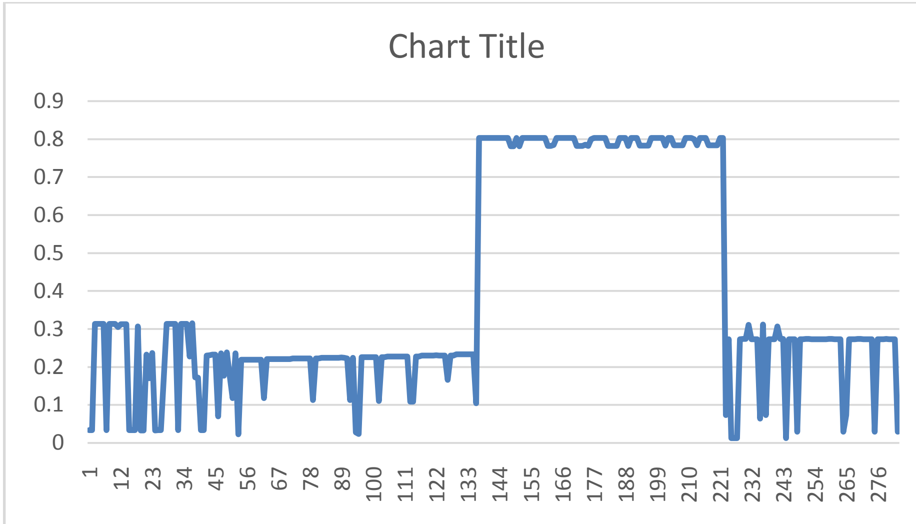

Fig. 17 – Standard Deviation

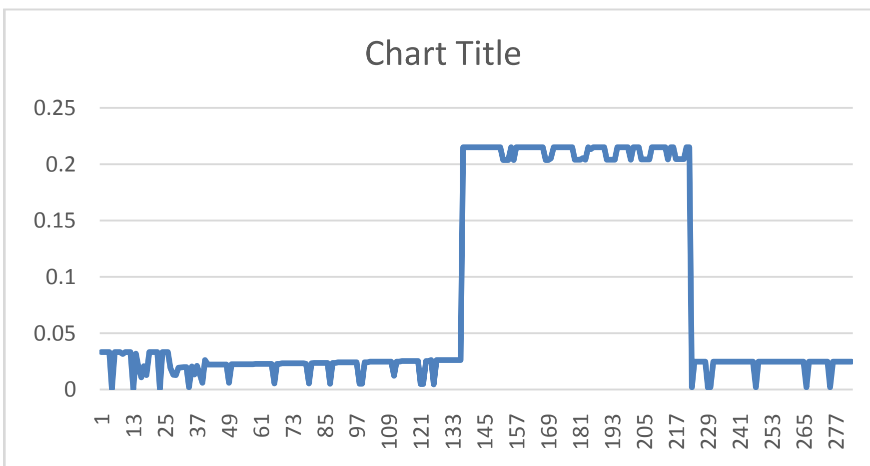

Fig. 18 – Variance

7. Performance Analysis

In this section, some of the commonly used techniques are compared with the performance of proposed passive disturbance technique. The new and conventional strategies are compared for various disturbances (E1, E2, E3, E4, E5, E6, E7 and E8) in the microgrid model under different operating conditions respectively). These figures demonstrate how effectively the proposed MSMGF and STMHT algorithms, respectively, identify the occurrence of the events. 2300 examples are produced when the disturbances and operational circumstances mentioned above are combined and exposed to the noise-free state. To keep the paper constraint, only a small number of simulation results have been displayed. The grid frequency fluctuates when a power system disruption like islanding happens, yet the suggested method accurately recognizes when it happens.

All of the methods discussed above can classify islanding and non-islanding disturbances, but they are unable to classify the precise nature of various non-islanding disturbances, such as capacitor bank switching and switching faults (i.e., L-g, LL-g, and LLL-g faults), distorted grid voltage, voltage swell, or voltage sag, or unbalanced load switching, which is thought to be a problem for future work.

8. Conclusion

In this paper, firstly it is tried to classify pure sine and PQ disturbances such as voltage sag, voltage swell, and voltage with harmonics, transients and flicker at power system frequency. Before classification stage, data is normalized then five PQ disturbances and pure sine are decomposed by using continuous wavelet filter and energy distributions of detail coefficients of PQ disturbances and pure sine are obtained. Pure sine is taken as a reference.

When looking at variations in feature vector for PQ disturbances signals and pure sine, it is seen they are distinguished as visual and also data size is reduced. This thesis proposed two kinds of classification algorithms for the disturbance types considered and could successfully use one of those algorithms to achieve a very high error classification rate. The use of wavelet multi-resolution analysis standard deviation curves. Also, the insights provided in this thesis on using clustering-based wavelet MRA energy parameters along with Adaptive Resonance theory classification algorithms is worth further investigation.

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