# Comparison Among Advanced Algorithms ForHarmonic Detection

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**ABSTRACT:** This paper aims to make a thorough comparison of some of the techniques used for harmonic detectionwith special emphasis on Prony Analysis, Singular Value Decomposition (SVD) and Multi - Resolution Analysis (MRA). The study will be done to check the accuracy and effectiveness of the methods with the benchmark being set by Fast Fourier Transform (FFT). Further on these methods have also been discussed as potential health checkers of the circuit. Using these methods, the time of occurrence of the faults can be analyzed

**Keywords -** Fast Fourier Transform, Prony, Singular Value Decomposition, Wavelet Transform, Multi - Resolution Analysis

## I. INTRODUCTION

Harmonics are an integral yet unnecessary part of the line voltages and currents being used to power our everyday appliances. A non-linear load draws a current which is not perfectly sinusoidal. This results in the current waveform getting distorted which in turn distorts the line voltage waveform. Harmonics adversely affect all powersystem equipment and thus a clear knowledge of the amount of harmonics present becomes absolutely essential. The Fourier Transform is a conventional method to analyze the harmonic content. However, it has several short-comings like it cannot be applied for analysis of non-stationary signals and also it has problems of leakage error and the picket-fence condition [6],[7]. It also needs a time window of at least one cycle of the lowest frequency component to detect all the harmonics thus making it a slow method for online computations. To overcome the problems, many alternatives have been proposed. Some such techniques like the Prony Analysis, SVD, Wavelet Analysis and MRA are being investigated here. A code was written in MATLAB to perform the Prony and SVDanalysis [2]. In order to test the efficacy of the code, a test case was introduced. After the codes were able to produceaccurate results, they were applied on the Simulink models of a) A three phase rectifier circuit and b) A three phasefault circuit. For the models, the FFT Analysis was taken as the benchmark. This was followed by a thorough comparison between the different harmonic detection techniques [4]-[5]. A brief description of the techniques is given below:

### A. Prony Analysis

It actually extracts valuable information from a uniformly sampled signal and builds up a series of damped sinusoids. This allows for the estimation of frequency, amplitude, phase and damping coefficients of a signal. Prony Analysis uses a linear prediction model for the estimation of harmonics. The main contribution of this method is that it actually converts a non-linear approximation of exponential sums by solving a set of linear equations and a root finding problem.[1]-[2], [5],[8]

### B. Singular Value Decomposition

Singular Value Decomposition (SVD) is all about exposing the substructures of a matrix i.e., exposing the basic elements that make up the matrix. SVD works by decomposing high dimensional largely variable data points into low dimensional sub-structures. This technique vastly reduces the amount of data required for calculations as it can very easily filter out the “useful” data below a certain threshold. SVD actually transforms correlated variables intouncorrelated set of data points that expose original behaviour and helps in sorting data on the basis of variations infewer dimensions.[8] In this discussion this technique has been modified to extract harmonics from output currentwaveforms of various models discussed here.

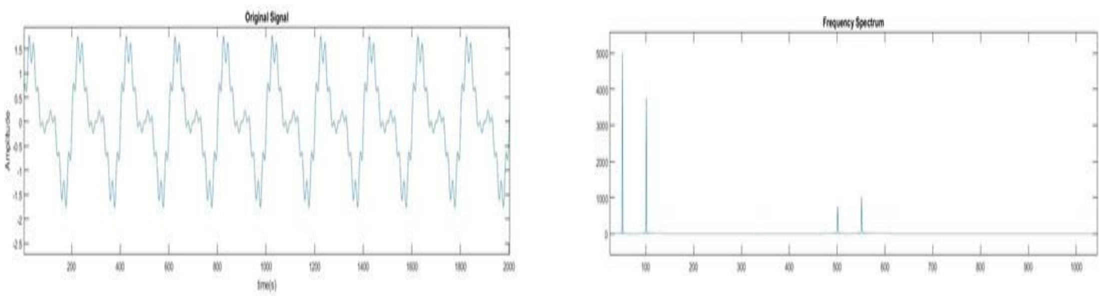
**C. Multi-resolution Analysis**

Multi-resolution Analysis (MRA) is one of the best methods if the main aim is to focus on both time and frequency information in a signal i.e., it gives us a clear idea of the different harmonics present at different instances of time." [3] In order to find out the frequency components in the various parts of the continuous signal and to analyze the signal by the multi-resolution analysis, a Scalogram is plotted. The Scalogram actually gives an idea about the percentage of energy for each coefficient.

## II. HARMONIC ANALYSIS

**A. Test Case**

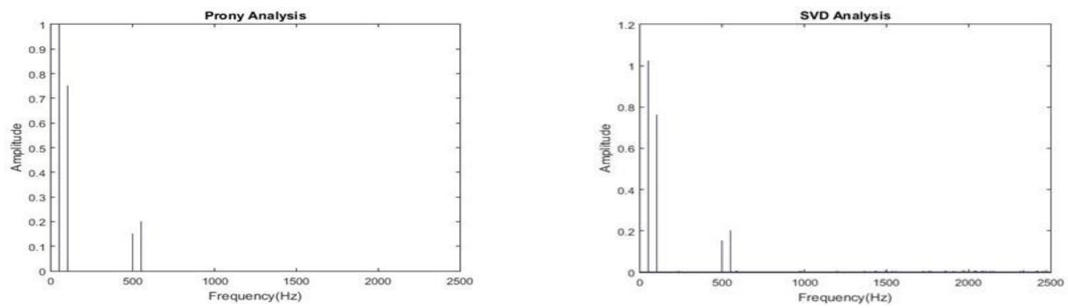
An input signal is taken which has a fundamental component of 50 Hz along - with some very low amplitude high frequency harmonics (known before-hand).




(a) Original Waveform (b) FFT Analysis

**Figure 1: Original Waveform and its FFT Analysis**

In Figure 1(a) above, the original signal waveform is shown along with its FFT Analysis in Figure 1(b). On performing Prony analysis and SVD Analysis over this, the following figures were obtained:




(a) Prony Analysis (b) SVD Analysis

**Figure 2: Prony and SVD Analysis of Original Waveform**

As there was no noise in the test signal, so all the methods gave quite accurate results which are analyzed below. Prony Analysis works perfectly due to the absence of noise. The harmonic analysis data obtained in Figure 1 and Figure 2 are represented in Table 1 below and it is observed that the amplitude thrown up by SVD is slightly inaccurate and also some extra harmonics with very negligible amplitude throws up randomly. This may be accounted for by the fact that the singular values howsoever small is not represented by zero. So, a minimum threshold if provided for, in the code solves this inaccuracy. The recorded data in tabular form is as below:

**Table - 1**

| Frequency (Hz) | | | Amplitude | | |
|---|---|---|---|---|---|
| FFT | Prony | SVD | FFT | Prony | SVD |
| 50 | 50 | 50 | 1 | 1 | 1.02 |
| 100 | 100 | 100 | 0.75 | 0.75 | 0.76 |
| 500 | 500 | 500 | 0.15 | 0.15 | 0.152 |

| | | | | | |
|---|---|---|---|---|---|
| 550 | 550 | 550 | 0.20 | 0.20 | 0.201 |

Now using Simulink, a three-phase rectifier and a three-phase fault were simulated. The above-mentioned methods were all applied on the output load currents and the results are discussed in detail.

**B. Three Phase Rectifier**

**i. No fault**

A three-phase rectifier circuit was simulated using SIMULINK and the output load current waveform drawn by an R-L load is displayed below in Figure 3.

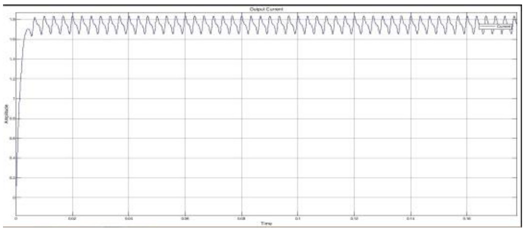
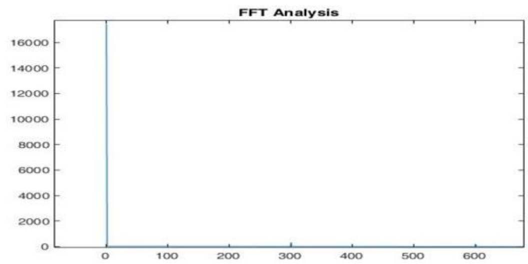
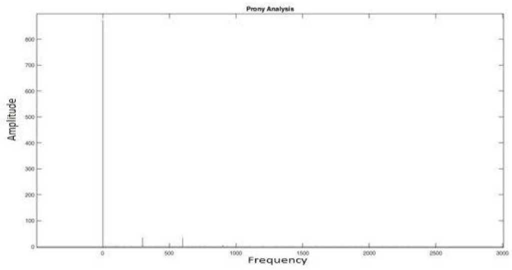


**Figure 3: Waveform of load current**

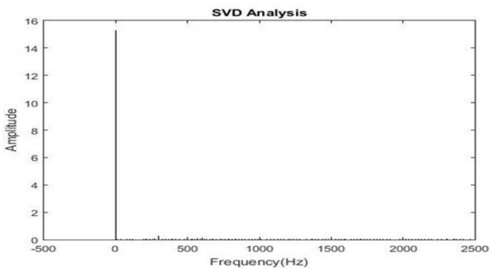
As can be seen, the load current is dc as expected. It is obvious that the dominant component will be the 0 Hz component followed by the 300 Hz component,600 Hz component and so on. The current is sampled and the data file generated thus serves as an input to the programs written for harmonic analysis by the various methods. The results (showing the relevant amplitudes of the frequency components present) are displayed below in Figure4 (appropriate captions are provided to distinguish between the different methods).



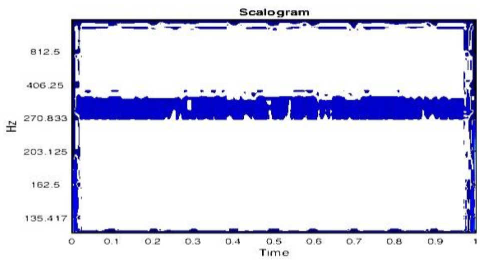

(a) FFT Analysis




(b) Prony Analysis




(c) SVD Analysis



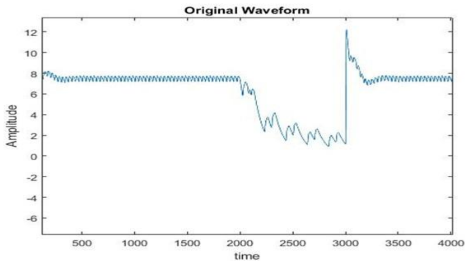

(d) MRA Analysis

**Figure 4: Harmonic Analysis of load Current Waveform**

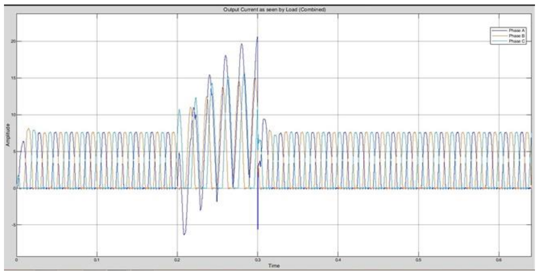
It is very interesting to note that in the multi-resolution analysis we see that the 300 Hz component is presentin substantial quantity all throughout time. However according to SVD, Prony and FFT, the dominant componentis the dc component i.e., the 0 Hz component.

**ii. Accidental short circuit across the diode**

In this case, a short circuit is introduced across one of the diodes in the rectifier for the time period of 0.2-0.3seconds. Figure 5(a) shows the output current waveform with the fault interval highlighted: The figure 5(b) belowshows the input current waveform:



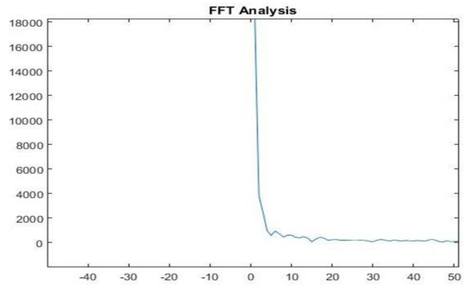

(a) Original Waveform with fault



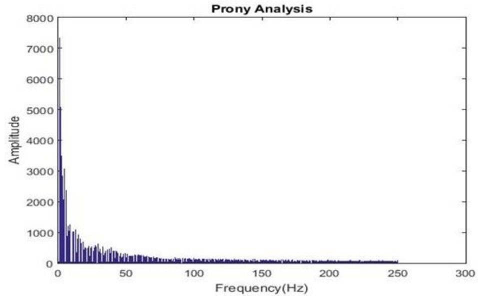
(b) Input Waveform

**Figure 5: Original Waveform and the Input waveform**

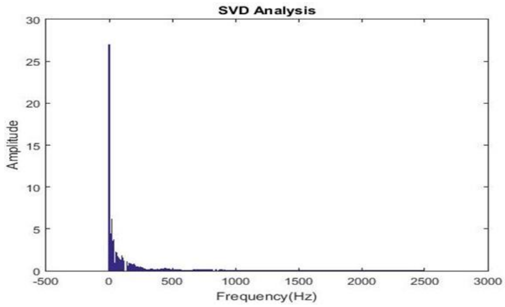
Now, the FFT, Prony, SVD and MRA analysis is shown below:



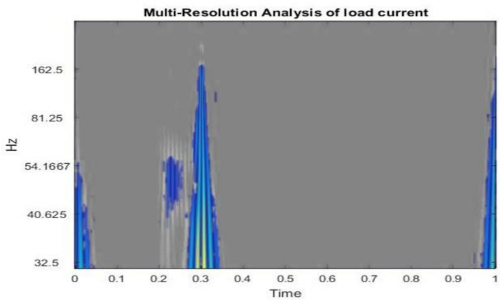

(a) FFT Analysis




(b) Prony Analysis



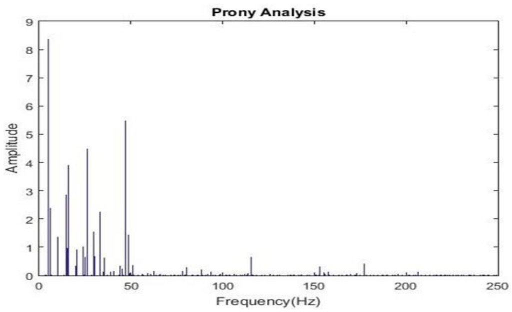

(c) SVD Analysis



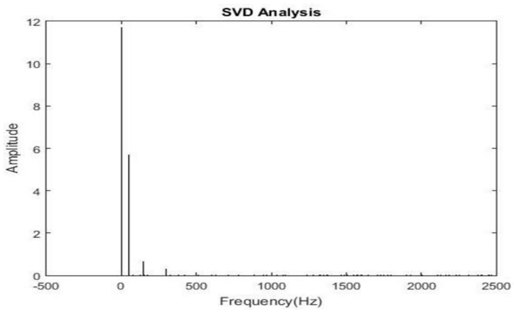

(d) MRA Analysis

**Figure 6: Harmonic Analysis of the Waveform**

After the analysis on the whole-time interval is completed, the same frequency analysis is done only during thetime the fault occurs (0.2 to 0.3 seconds) The Prony and SVD analysis are demonstrated below in Figure 7:




(a) SVD Analysis



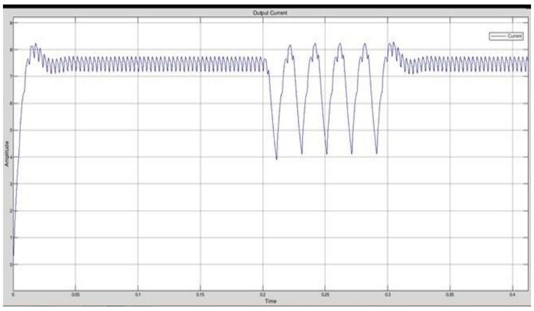

(b) MRA Analysis

**Figure 7: Prony and SVD Analysis of the duration of fault**

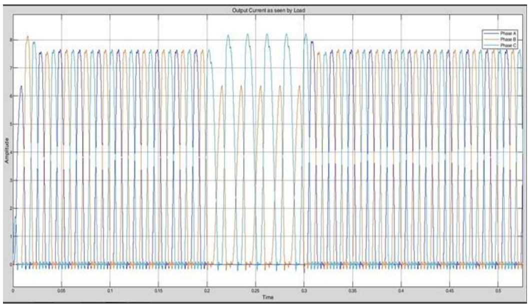
The FFT Analysis could not be performed on that time interval because the data for a complete cycle was notprovided.

**iii. Accidental open circuit across the diode**

In this case, an open circuit occurs across the diode for the time period of 0.2-0.3 seconds. Figure 8(a) shows the output current waveform with the fault interval highlighted: Next Figure 8(b) shows the input current waveform:



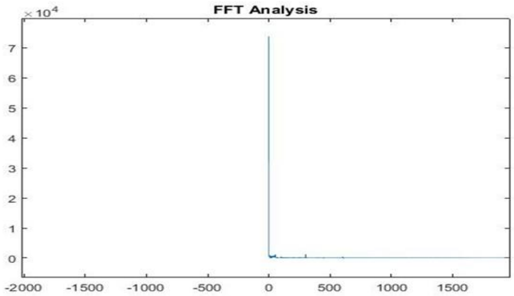
(a) Original Waveform with fault



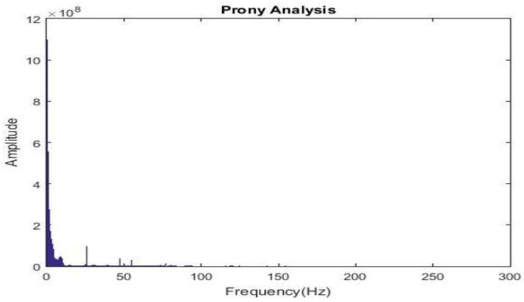
(b) Current Waveform seen by load

**Figure 8: Original Waveform and the Current waveform**

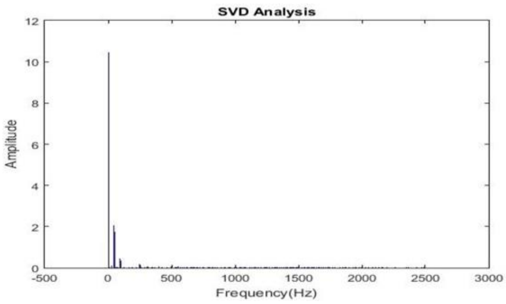
Now, the FFT, Prony, SVD and MRA analysis is shown below in Figure 9:



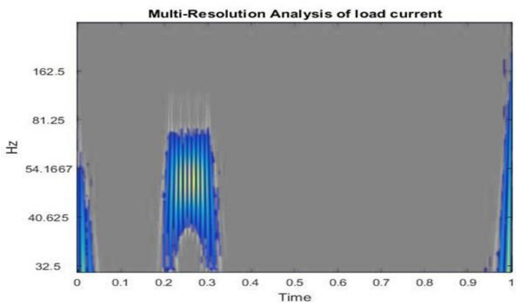

(a) FFT Analysis




(b) Prony Analysis



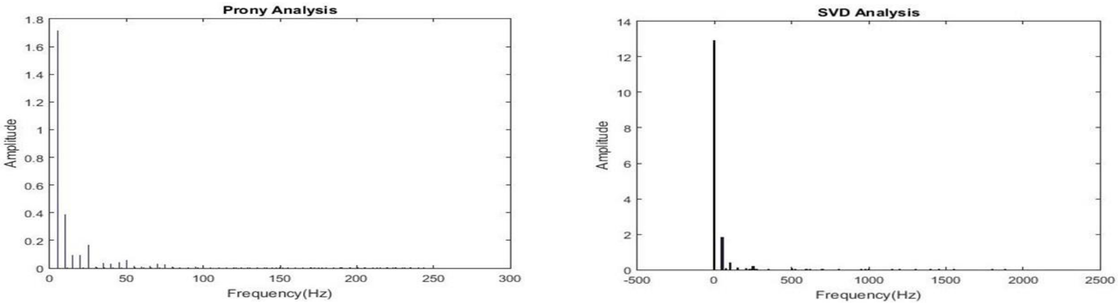

(c) SVD Analysis




(d) MRA Analysis

**Figure 9: Harmonic Analysis of the Waveform**

After the analysis on the whole-time interval is completed, the same frequency analysis is done only during thetime the fault occurs (0.2 to 0.3 seconds) The Prony and SVD analysis are demonstrated below:




(a) Prony Analysis (b) SVD Analysis

**Figure 10: Prony and SVD Analysis of the duration of fault**

The FFT Analysis could not be performed on that time interval because the data for a complete cycle was notprovided.

**C. Three Phase Fault**

**i. Three phase unbalanced line to ground fault**

Using SIMULINK, a three-phase unbalanced fault was simulated with a line to ground fault in Phase B. Figure11 shows the load current waveform obtained:

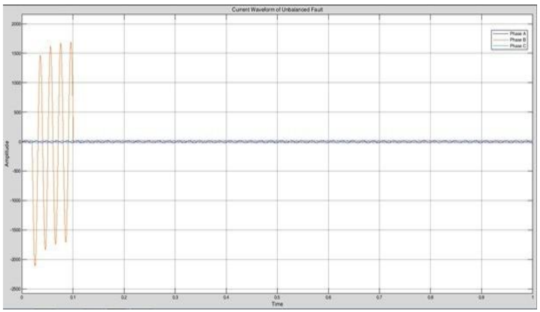
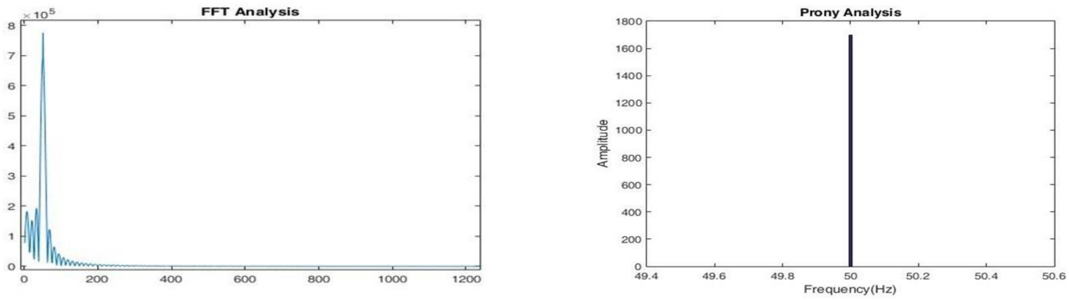
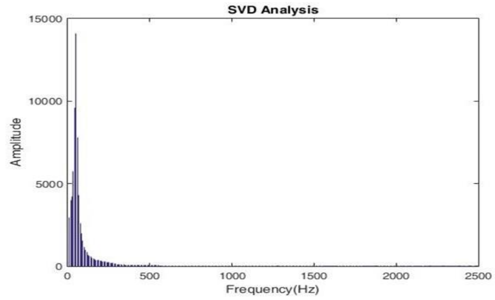


**Figure 11: Current Waveform**

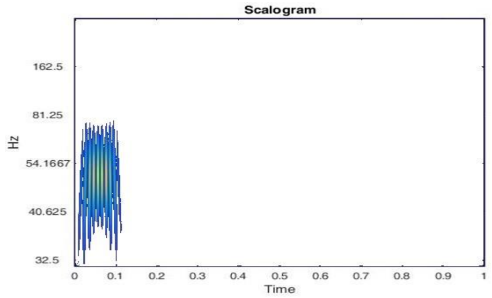
Analysis was performed separately on the three phases. Phase B being the faulted phase, showed differentresults compared to the other two phases, which were similar in nature.
The results obtained for phase B are shown below in Figure 12:




(a) FFT Analysis (b) Prony Analysis



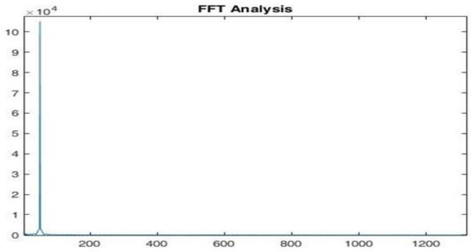

(c) SVD Analysis



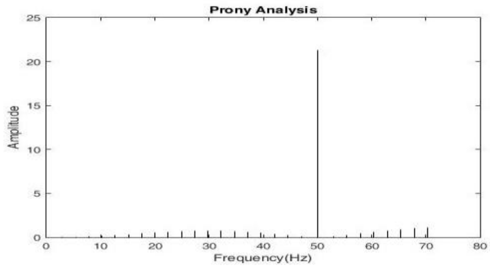

(d) MRA Analysis

**Figure 12: Harmonic Analysis of Phase B**

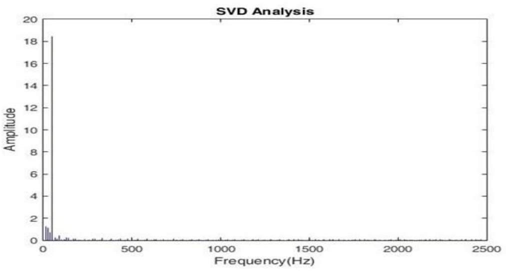
As we can see from the load current waveform, during the fault the current in phase B increased manifold. Thisis because, since there is a shorting between line and ground, neutral has shifted to that point and large line to ground current flows. This is highlighted in the harmonics present in phase B which is very prominent in the SVD of phase B. The results obtained for Phase A and C are demonstrated in Figure 13 below:



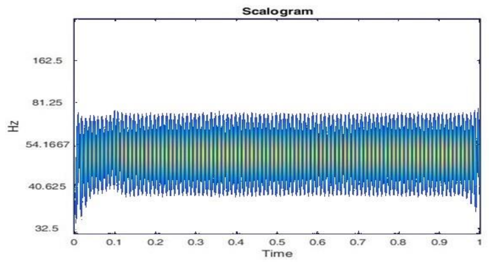

(a) FFT Analysis




(b) Prony Analysis




(c) SVD Analysis




(d) MRA Analysis

**Figure 13: Harmonic Analysis of Phase A and Phase C**

From the above graphs, we can clearly see that there is no change in the load current in these two un - faulted phases and the frequency spectrum is also much more harmonic - free as compared to the faulty phase B. This whole discussion emphasizes on the fact that harmonic analysis is a very effective method for analyzing fault. If this technique is employed in a software maintaining the health of a circuit, then it can essentially detect when fault occurs. This is because during a fault (short circuit or open circuit) several harmonics are introduced in the faulted phase as compared to the un - faulted phase. So, over a continuous process, as harmonics creep into the frequency spectrum one can detect/conclude that a fault is occurring in the circuit. Subsequent actions can be taken thereafter. Now the whole discussion has been summarized in the next section.

## III. CONCLUSION

If no White Gaussian noise is present, then Prony is the best method as it requires very less data, time and can separate between very closely placed frequencies. SVD works perfectly in most cases but requires more datapoints. Multi-resolution Analysis gives an idea about the dominant frequency band and the time intervals in whichit is prevalent. This analysis is, therefore, effective for detecting sudden disturbances or changes of signal values.When White Gaussian Noise is present, then, Prony method fails completely. This is because it is a linear prediction model which means that it requires the past values, analyses them and tries to fit the future values in the model.

This works fine as long as the signal is periodic and there is no noise and so all the values perfectly fit. Once,the random noise is introduced, the signal no longer fits into the definition of a linear model and so the results become erroneous and the method, ineffective. SVD Analysis is quite effective and gives accurate results even when noise is introduced in the signal. In the three-phase rectifier case, it is seen that the maximum amplitude is the dc component as seen in Figure 4(a). When the accidental faults occur, harmonics are introduced in the systemas seen in Figure 6. From the multi-resolution analysis it is confirmed by the blue patches that very high quantities of harmonics are introduced by the fault. This vastly affects rectifier efficiency. However, MRA throws up 300 Hz as the dominant frequency. For the three-phase fault analysis, it is seen from Figure 12 that fault introduces alot of harmonics. The un - faulted phase analysis results on the other hand, shows a smooth peak at 50 Hz (without the introduction of much significant harmonics). In multi-resolution analysis results, one expects a dominant 0 Hz component to show up throughout the entire time interval but it is not the case. This can be attributed to the fact that multi-resolution analysis actually gives the least resolution to lower frequencies and the dc component showsup only in areas where it is given enough weight to be reflected. Hence this method cannot be used to determine very closely spaced frequencies but gives a basic idea of the fault as can be seen in the preceding discussion. To get a more accurate idea of the harmonics introduced by the fault, SVD and Prony analysis are fairly accurate. As it can be seen from Table-1, the codes used in this discussion (developed by the authors) gives fairly accurate results with very minimal error in frequency estimation. The amplitudes however become more accurate once more data points are taken into consideration. Due to technical limitation, the no of samples in each iteration couldnot exceed more than 10,000 data points. Finally, it can be concluded that SVD, Prony and MRA are much moreefficient and robust methods as compared to FFT.

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