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Frequency Estimation Using Top-Hat Transforms

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Abstract: In signal processing, frequency estimation is an important step to detect and analyse power quality disturbances. In general, conventional strategies based on Fourier transforms have been applied for this purpose. In this paper, a new strategy in estimating the frequency of the signal in time domain is presented. This proposed strategy is based on top-hat transforms. The signal is processed using both transforms, then the results are compared to find the frequency estimation of the signal. By simulating this strategy using Matlab, the results show good estimation for noise-free signal and signal with SNR at higher than 30dB. The accuracy of the results decreases when analysing the signal with SNR less than 30dB.

Keywords: *transforms, Mathematical Morphology, power quality, Top-hat transforms.*

I. Introduction

Several methods for frequency estimation have been applied on the signal such as Zero Crossing method [1,2]. This method has good performance for well filtered or perfect waves. It also has a high sensitivity to noise. Prony algorithm [3–6] also has a good performance in estimating the frequency in a signal. This proposed which gives reliable estimates in presence of noise but has a problem in the existent of the outliers due to the process on minimising the error between the estimated signal and original signal.

Another method for estimating frequency is Kalman filter [7]. This method is suitable for noise rejection, but it has a drawback where the process is slower compared with other methods. This method is dependent on the model parameters adjustment (variance and covariance noise matrices).

Demodulation is also can be used to estimate the frequency [2]. The main idea for this method is to multiply the scalar input with a sine and cosine signal with a known frequency. This has a sensitivity to large negative sequence component especially for fault conditions.

Phasor measurement angle changing [8] is also able to estimate the frequency signal. This method uses a positive sequence phasor estimation. This method presents satisfactory results under large frequency variations and is used in commercial PMUs.

In this chapter, the new strategy in estimating the frequency of a sinusoidal signal is presented. Even though for frequency estimation, the phasor angle changing method and demodulation strategy generated satisfactory results, but this strategy gives an alternative for the future application. This is because this method is based on mathematical morphology, the method that just needs some simple calculation.

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II. Method

Top-hat Transforms

The strategy in estimating of the frequency of the signal is based on top-hat transforms. The input signal f(x) is initially processed using top-hat SEs with value of structuring element (g) = 3 that can be denoted as follows:

$$T_{HAT} = f - (f \circ g) \qquad (1)$$

The effect of top-hat transforms on the signal can be seen in Figure 1. A small magnitude represent the peak of the signal in positive value is generated when the signal is processed using the top-hat transform while a negative value is generated by using the transform.

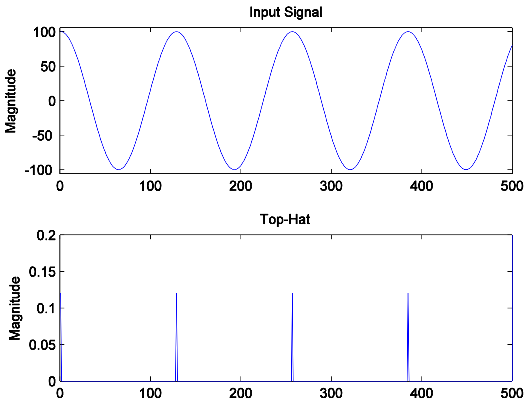

Figure 1. Effect of top-hat transforms on the signal

Frequency Calculation

Results of top-hat transforms in a signal is used to estimate the frequency of the signal by calculating the location time between the peaks of the signal. The result of the top-hat transform as a vector or matrix (1 × *m*) are then used to find the frequency estimation of the signal. From this matrix, the row number of the elements that contain zero value are deleted, and non-zero values is recorded as a new matrix $T_{n1}(n)$ as follows:

$$T_{n1(n)} = \begin{cases} n & ; T_{n1(n)} > 0 \\ [-] & ; T_{n1(n)} = 0 \end{cases} \qquad (2)$$

where n =1, 2, 3, ... , m and m is the length of the processed samples. Then every element of the matrix T_{n1} is subtracted to become a new matrix T_{n2} using this formula:

$$T_{n2}(n-1) = T_{n1}(n) - T_{n1}(n-1) \qquad (3)$$

From these results, the frequency estimation (f_{es}) can be calculated using the following formula:

$$f_{es} = f_s / \max(T_{n2}) \qquad (4)$$

where f_s is the sampling frequency. By choosing the maximum value of T_{n2}, the values from the top-hat transforms process that represent the noise in the signal can be eliminated.

III. Simulation and Results

There were some simulations undertaken using Matlab. This proposed strategy was used to calculate the frequency of the signal in different conditions; noise free signals and signals

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containing noise. All signals were analysed in different frequencies and different values of SNR. The sampling frequency for all simulations was 6.4 kHz with a structuring element (g) = 3.

3.1. Noise-free Signal

For the noise-free signal, the estimation process using the top-hat transform can be seen in Figure 2 to 4.

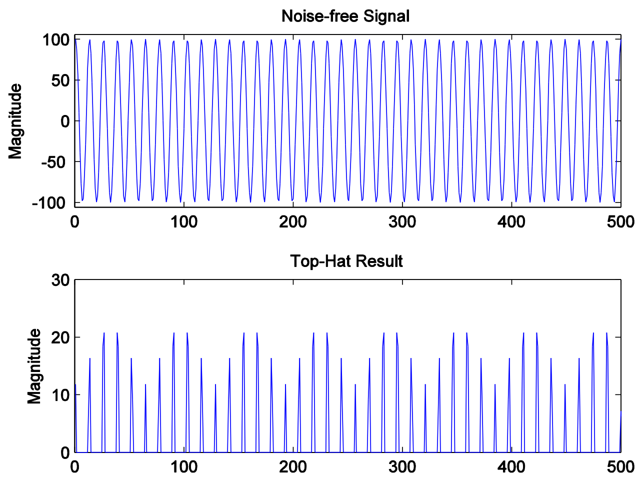

Figure 2: Results of top-hat transform for a noise-free signal

Figure 3 is the comparison of actual frequency and frequency estimation using the top-hat transform for noise-free signal. The errors in this method increase gradually following the increase of the frequency. This error can be seen in Figure 4. For frequencies 30 to 60 Hz, the error is less than 1% while at 300 Hz it becomes 5% and at 500 Hz it is about 8%.

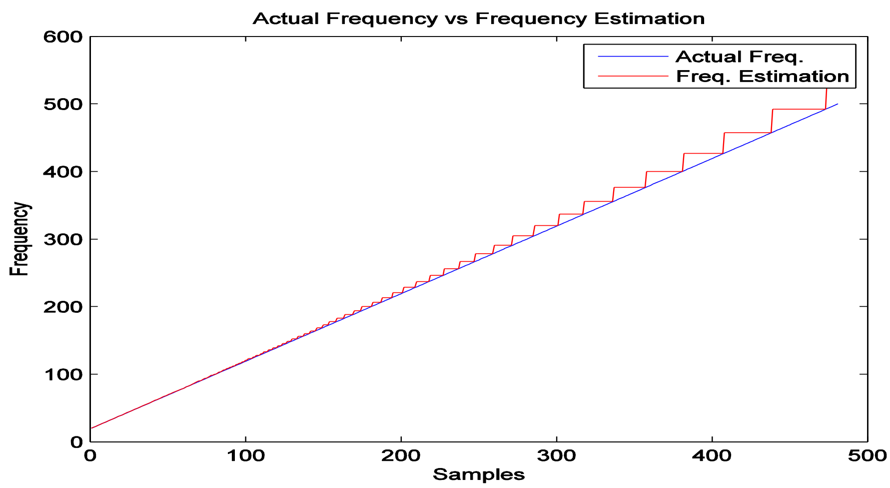

Figure 3: Actual frequency vs estimated frequency for noise-free signal

In Figure 3 the shape of the error is unique. It has a stair shape with some of the errors are zero or near zero with the largest error is just about 8% for a frequency of 495Hz. This means that some frequency is estimated correctly by this strategy especially for noise-free signals.

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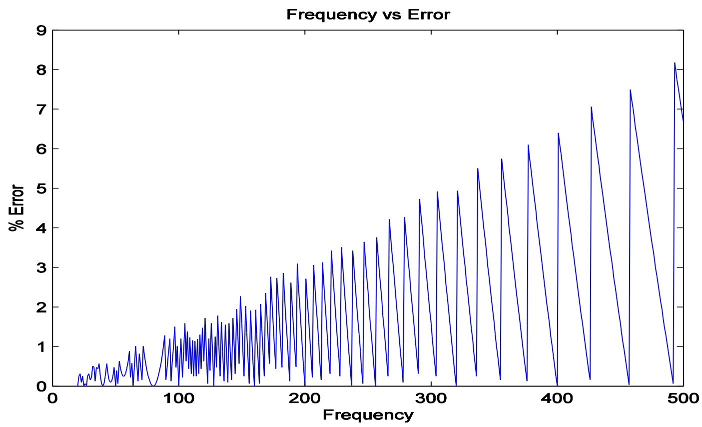

Figure 4: frequency vs error for noise-free signal

3.2. Signal with Noise

The simulation has also been undertaken using different values of signal to noise ratio (SNR) to show the effect of noise on the signal.

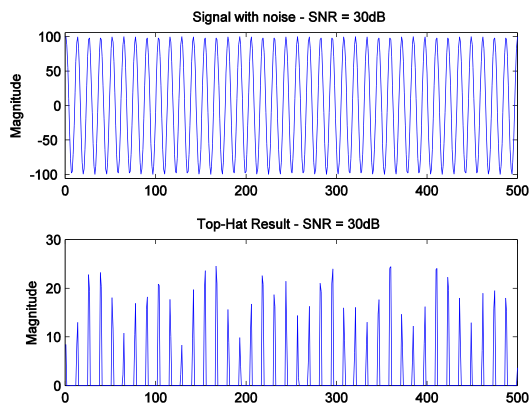

Figure 5: Results of top-hat transform for signal with SNR=30dB

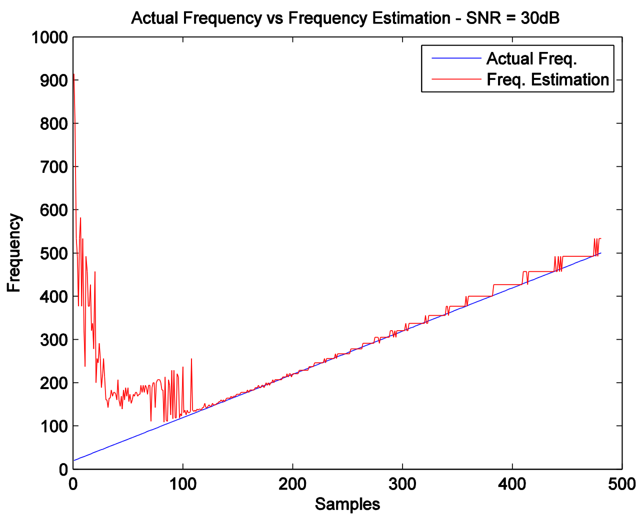

Figure 6: Actual frequency vs estimated frequency for 30dB signal

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Figures 5 to 7 show the estimation process using top-hat transform or signal with SNR=30 and the frequency varying from 20Hz to 500Hz. It is clearly seen in Figure 6 that this method has a difficulty in detecting frequency lower than 110Hz. In this frequency range, the errors are high while in the frequency over 110Hz this method generates a better result. The error in this condition can be seen in Figure 7 for the different frequency.

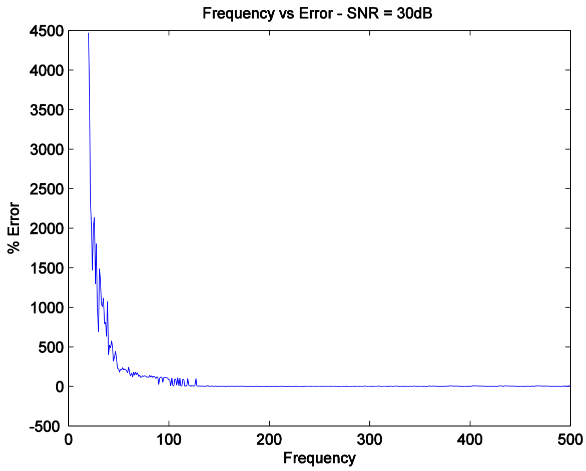

Figure 7: frequency vs error for signal with SNR=30dB

The error for the frequency of lower than 100Hz happens due to the availability of noise in this signal. This noise is processed by the top-hat transforms making this strategy generate an imprecise estimation. The more noise exists in the signal, the higher the frequency estimation is produced. For example, the result for a signal with frequency of 40Hz is 400Hz or ten times higher than the expected frequency which is shown in Figure 7.

3.3. Signal at various frequencies

Figure 8 shows the results of the top-hat transform for a frequency of 100Hz. The actual frequency versus estimated frequency for varies SNR (from 0dB to 100dB) at frequency 100Hz can be seen in Figure 9. The error increased when the SNR was lower than 35 dB. This means that more noise makes more errors in this method as can be seen in Figure 10.

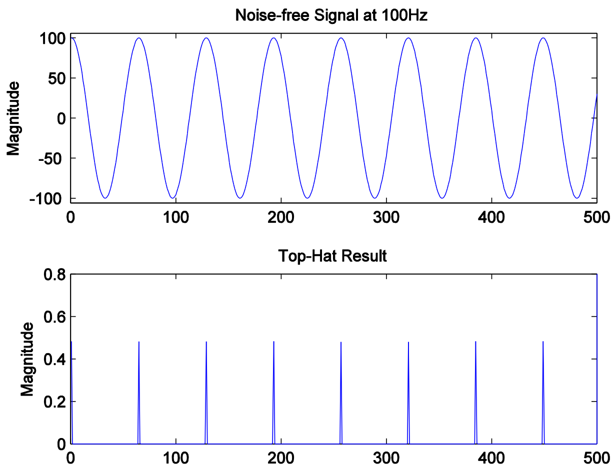

Figure 8: Results of top-hat transform for a noise-free signal at 100Hz

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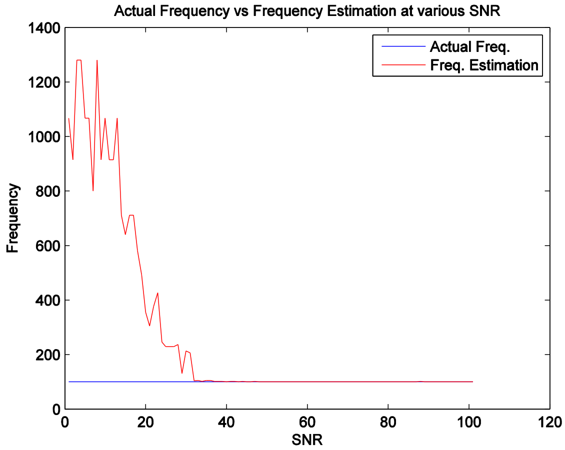

Figure 9: Actual frequency vs estimated frequency at 100Hz

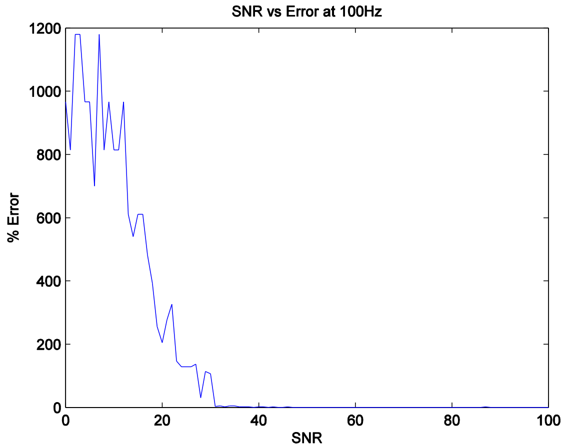

Figure 10: frequency vs error at 100Hz

For the signal with a frequency of 100Hz, the strategy has good results when the SNR value is larger than 35dB.

This strategy successfully estimates the frequency of the signal at 300Hz when the signal has SNR value greater than 18dB. It can be seen in Figures 11 to 13.

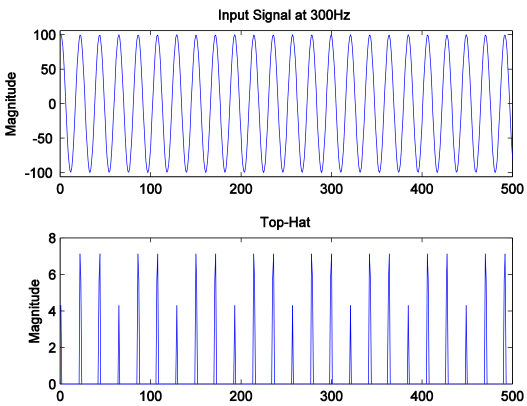

Figure 11: Results of top-hat transform for a noise-free signal at 300Hz

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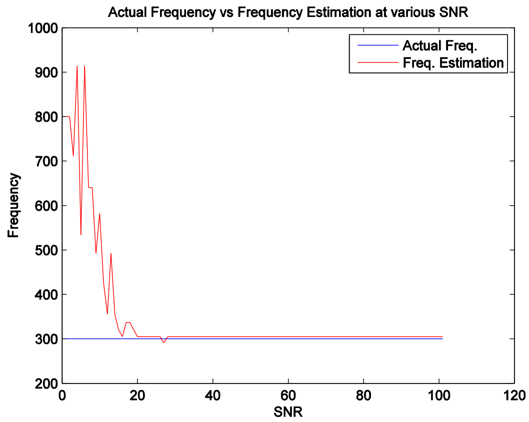

Figure 12: Actual frequency vs estimated frequency at 300Hz

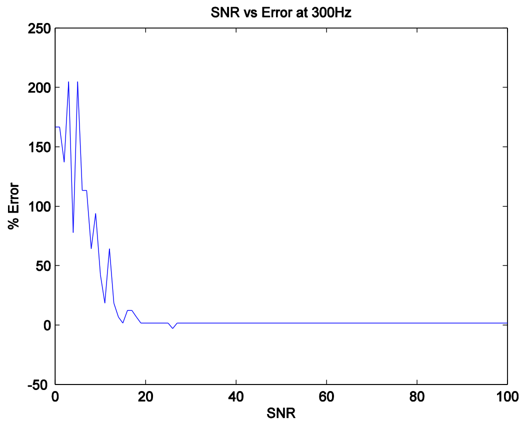

Figure 13: frequency vs error at 300Hz

At 500Hz, error for this strategy is less than 10% of the actual frequency when the SNR value of the signal is bigger than 8dB, and it can be seen in Figures 14 to 16.

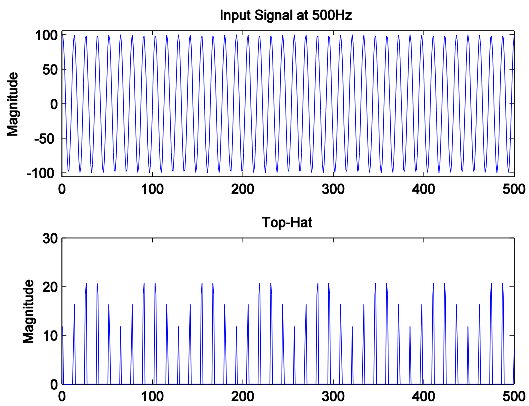

Figure 14: Results of top-hat transform for a noise-free signal at 500Hz

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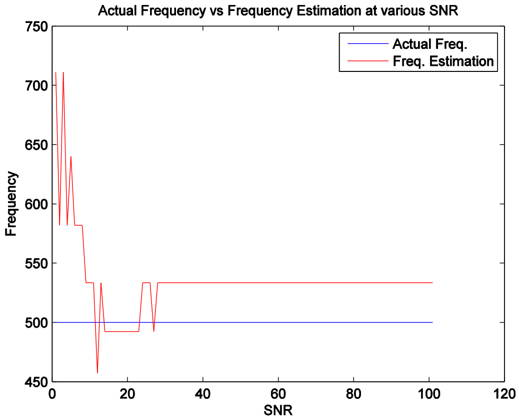

Figure 15: Actual frequency vs estimated frequency at 500Hz

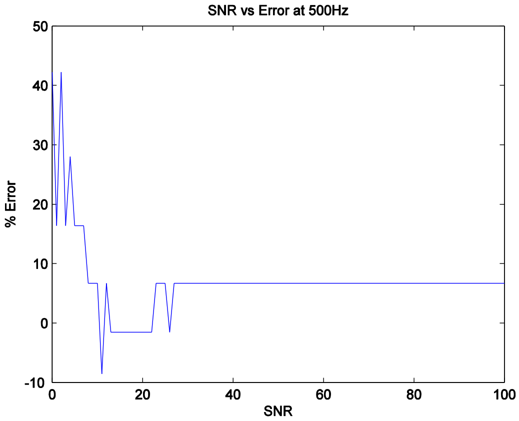

Figure 16: frequency vs error at 500Hz

Successful results have been made for this strategy when the signal has a frequency of 800Hz with SNR is higher than 1. The simulation results for this frequency can be seen in Figures 17 to 19.

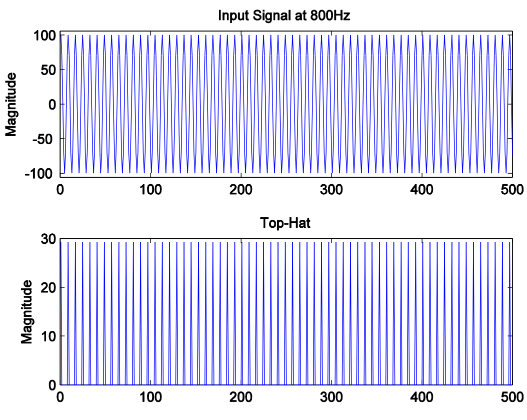

Figure 17: Results of top-hat transform for a noise-free signal at 800Hz

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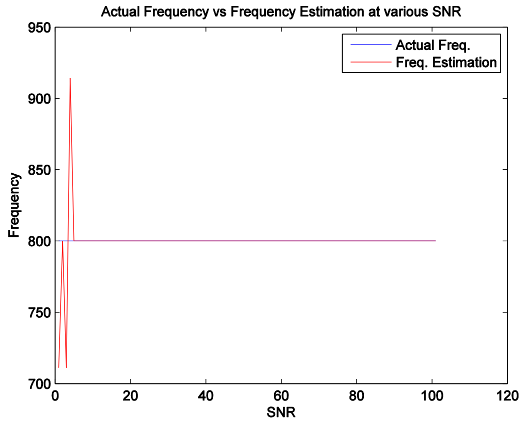

Figure 18: Actual frequency vs estimated frequency at 800Hz

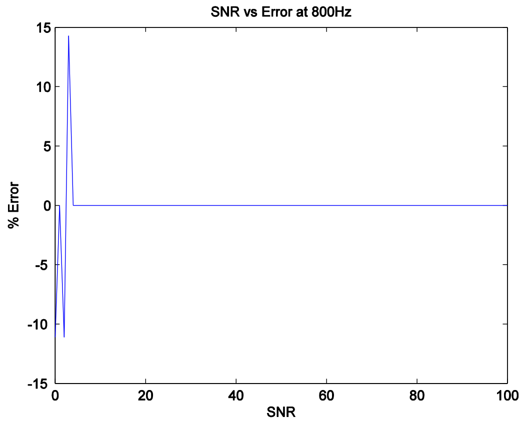

Figure 19: frequency vs error at 500Hz

The proposed method also has been tested for frequency of 1kHz. The results can be seen in Figures 20 to 22.

The error for the signal at 1kHz is 6.5% of the actual frequency for the SNR greater than 8dB, while the estimated frequency dropped to 8.5% below the actual frequency for SNR between 0 to 8dB.

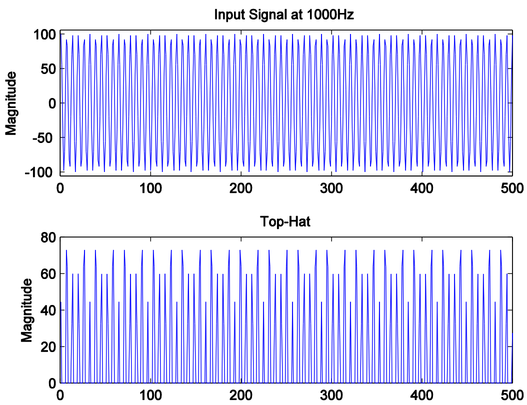

Figure 20: Results of top-hat transform for a noise-free signal at 1kHz

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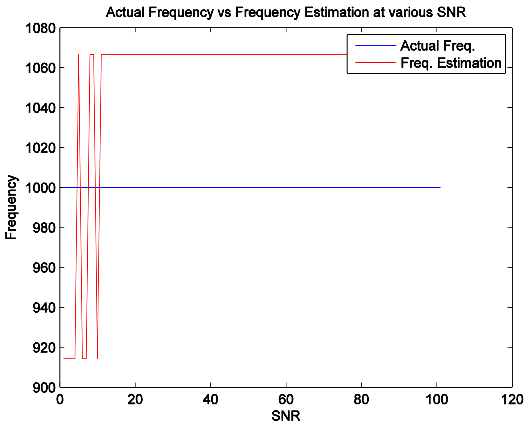

Figure 21: Actual frequency vs estimated frequency at 1kHz

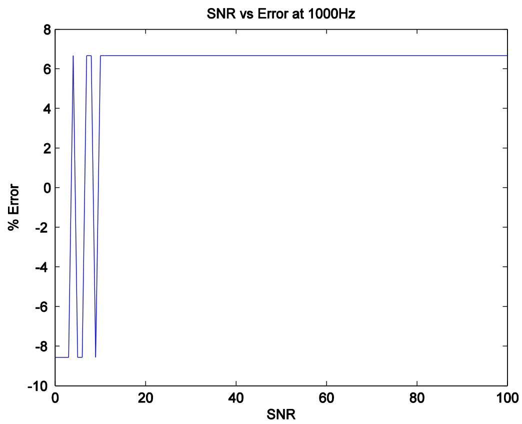

Figure 22: frequency vs error at 1kHz

IV. CONCLUSION

This proposed strategy is based on the top-hat transforms to estimate the frequency of the signal. The results show this method can handle low frequencies when the signal is a noise-free signal while this method cannot handle low frequency, especially lower than 40Hz, in the signal containing noise with SNR below 30 dB. For various values of SNR, the higher the frequency the better results have been obtain with the optimum result at frequency 800Hz. This method is an alternative method in estimating the frequency of a signal. By using MM, the burden in calculation when using traditional methods can be reduced.

V. REFERENCES

[1] C.T. Nguyen and K. Srinivasan, “A new technique for rapid tracking of frequency deviations based on level crossings,” IEEE Transactions on Power Apparatus and Systems, vol. PAS-103, no. 8, pp. 2230–2236, Aug 1984.

[2] M. M. Begovic, P. M. Djuric, S. Dunlap, and A. G. Phadke, “Frequency tracking in power networks in the presence of harmonics,” IEEE Transactions on Power Delivery, vol. 8, no. 2, pp. 480–486, Apr 1993.

ISBN : 978-602-99806-3-9

[3] S. Rai, D. Lalani, S. K. Nayak, T. Jacob, and P. Tripathy, “Estimation of low-frequency modes in power system using robust modified prony,” IET Generation, Transmission Distribution, vol. 10, no. 6, pp. 1401–1409, 2016.

[4] S. R. Nam, S. H. Kang, L. M. Jing, S. H. Kang, and S. W. Min, “A novel method based on prony analysis for fundamental frequency estimation in power systems,” in IEEE 2013 Tencon - Spring, April 2013, pp. 327–331.

[5] J. Li, S. Wang, and F. Wang, “Frequency estimation by correlation based two dimensional prony-type method, ” in International Conference on Neural Networks and Signal Processing, 2003. Proceedings of the 2003, vol. 1, Dec 2003, pp. 681–685 Vol.1.

[6] T. Lobos and J. Rezmer, “Real-time determination of power system frequency,” IEEE Transactions on Instrumentation and Measurement, vol. 46, no. 4, pp. 877–881, Aug 1997.

[7] M. S. Sachdev, H. C. Wood, and N. G. Johnson, “Kalman filtering applied to power system measurements for relaying,” IEEE Power Engineering Review, vol. PER-5, no. 12, pp. 52–53, Dec 1985.

[8] A. G. Phadke, J. S. Thorp, and M. G. Adamiak, “A new measurement technique for tracking voltage phasors, local system frequency, and rate of change of frequency, ”IEEE Transactions on Power Apparatus and Systems, vol. PAS-102, no. 5, pp. 1025–1038, May 1983.