Mains Failure Detection using Fourier series

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ABSTRACT
For the purpose of avoiding disturbance to the computer based applications, mains failure detection is essential. This paper presents the detection of mains failure with frequency analysis technique. Fourier series based fundamental signal extraction and mains failure detection were simulated with MATLAB/SIMULINK software and results are analysed.

General Terms
Computer, UPS, switchover, Matlab/Simulink.

Keywords
Fourier series, Frequency, Fundamental signal, Mains Failure.

1. INTRODUCTION
Central processing unit (CPU) application systems such as computers are quite sensitive to momentary power failure of an ac power source, comparing with the other conventional apparatus. By this reason, Critical loads such as computer and other computerized medical equipments have internal switch mode power supply (SMPS). This provides power supply to the load for minimum one cycle period of input voltage on mains failure [1]. So to avoid disturbance, with in this period of time, load should switch over from AC mains supply to battery power supply. There is a much time delay between instant of AC mains failure and switch over of load from mains mode to inverter mode [2-4]. Therefore the proposed method of quick detection of mains failure performs adequate procedure such as saving data and immediate switch over of load.

Detection of power supply failure across AC power mains has two problems to be solved. Firstly, input harmonics drawn by nonlinear load reduces power quality. Harmonics are eliminated by Fourier series analysis and then the fundamental signal extracted is subjected to mains failure detection.

Secondly, Capacitor across AC mains supply used for purpose of power factor maintenance. On failure of mains, capacitor discharges through load with time,

$$\tau = RC \qquad (1)$$

Where C is value of input AC capacitor, R is load resistance. As capacitor value is larger, time taken to discharge is more. Therefore, failure of mains is detected slowly, after reaching the voltage zero. Slow detection results in larger switching time of load from mains mode to inverter mode so load will be subjected to disturbance resulting in loss of information. This can be avoided by detection of mains failure as early as possible.

Over the past several decades, significant progress has been made in developing alternative technologies to detect the mains failure as well as reduction of harmonics such as Phase lock loop (PLL), comparison with nominal voltage value, phase angle error calculation etc., The power quality disturbance caused by a single Personnel Computer (PC) produces 108.53% of current harmonic distortion and 73.6% of voltage harmonic distortion [1, 5]. The new technology is progressing impressively to make alternative power failure detects mains failure after one cycle on continuous absence of two pulses in digital detector [2, 3]. The other, Flexible control strategy for small wind turbines of 11kW operating in both stand-alone and grid connected mode detected grid failure on exceed of preset error in phase angle difference between grid voltage angle and phase angle created by PLL [6, 7]. Further, zero crossing detector circuit detects mains failure by detecting upward and downward transitions of the signal with Schmitt triggers combined in exclusive OR circuit [8]. Another method, digital converted AC signal is asserted when AC power is in vicinity of zero crossing and negated at all other times. Counter starts counting with asserted digital signal and ends with negated digital signal. Mains failure is detected if the counter equals or exceeds reference number before digital signal is negated [9]. In more previous method, Phase voltages are transferred from abc to αβ coordinate system and then to dq coordinate system. The amplitude obtained voltage vector is compared to threshold point to detect voltage sag or short interruption. Mains disturbance is detected when voltage reduces less than 70%, depending on failure at different point on wave [10].

Only few works have been carried out on mains/grid failure detection as a part of their research. By implementing new technique for mains failure detection provides way for innovations in the UPS technology. In this article, authors report their preliminary results for the detection of mains failure by using Fourier series.

2. METHODOLOGY
The simulation is based on Fourier series method for the detection of mains failure.

Fourier series of a periodic signal can be expressed using infinite trigonometric series of sine and cosine terms, as in (2) [11].

$$v(t) = a_0 + \sum_{k=1}^{\infty}(a_k \cos(k\omega t) + b_k \sin(k\omega t)) \qquad (2)$$

Where, a_0 , a_k , and b_k are coefficients,

$$a_0 = \frac{1}{T}\int_0^T v(t)dt \qquad (3)$$

$$a_k = \frac{2}{T}\int_0^T v(t)\cos(kwt)dt \qquad (4)$$

$$b_k = \frac{2}{T}\int_0^T v(t)\sin(kwt)dt \qquad (5)$$

Using Fourier series, fundamental frequency component of signal can be extracted by eliminating harmonic components. Required frequency component of input periodic signal can be extracted by multiplying input signal with sine and cosine term at the required frequency as shown in Figure. 1.

$$A\sin(k\omega t)\sin(k\omega t) = A\sin^2(k\omega t) = \frac{A}{2} - \frac{A\cos(2k\omega t)}{2} \quad (6)$$

$$B\cos(k\omega t)\cos(k\omega t) = B\cos^2(k\omega t) = \frac{B}{2} + \frac{B\cos(2k\omega t)}{2} \quad (7)$$

When sine function is multiplied by a unitary sine term at the required frequency, output of squared function contain DC component which is half reduced value of input amplitude. Squared sine function is of double frequency component of input signal as in (6). Similar result is obtained on multiplying cosine function with cosine term of same frequency as in (7).

Assuming mains AC input voltage to have constant frequency and known magnitude, frequency of the signal to be extracted at the output is selected by setting parameter k. Remaining frequency components are eliminated by low pass filter as shown in Figure. 1. The cut-off frequency of low pass filter is a function of fundamental frequency component. Therefore to extract 50Hz fundamental frequency component, frequency of sine and cosine terms is set to be 50Hz by setting parameter k equal to one. So the lowest frequency of the signal at the input of low pass filter is twice that of fundamental signal i.e. 100Hz. This implies the cut-off frequency of low pass filter to be at least one decade less than input, i.e. around 10Hz [12]. This is because frequency is in logarithmic function corresponds to ratio 1:10. This lower cut-off frequency results in slow dynamic response. If input contains DC components and sub harmonics, then cut-off frequency should have further reduced value

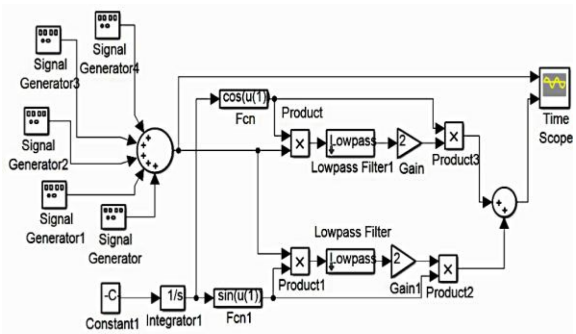

Fig. 1:Simulink model of Fundamental signal extraction

Obtained frequency domain signal is converted to time domain by multiplying the signal with exponential term, as in (8). This gives fundamental frequency signal in time domain.

$$v'(t) = \sum_{k=-\infty}^{+\infty} c_k e^{jk\omega t} \quad (8)$$

By using Euler's equations (9) and (10) in Fourier series expansion of the signal gives (11)

$$\cos\theta_k = \frac{e^{j\theta_k} + e^{-j\theta_k}}{2} \quad (9)$$

And $$\sin\theta_k = \frac{e^{j\theta_k} - e^{-j\theta_k}}{2} \quad (10)$$

Gives, $$v(t) = \sum_{k=-\infty}^{+\infty} c_k e^{jk\omega t} \quad (11)$$

This is the compact complex form of the Fourier series, in which positive and negative frequencies are considered.

Fourier series coefficient c_k, is a complex term expressed in frequency domain in response of real signal in time domain, as in (12). Mains failure is detected based on real component of Fourier series coefficient as shown in Figure. 2.

$$c_k = \frac{1}{T}\int_0^T v(t)e^{-jk\omega t}dt \quad (12)$$

Fourier series coefficient is generated for input signal based on which mains failure is detected. Real component of Fourier series coefficient is constant one for sinusoidal 230 V input signal. By using comparator and counter, mains failure is detected. Counter is designed such that it increments the count for every falling edge. Counter reaches one on mains failure, resulting in detection of mains failure which is then used to obtain signal as in Figure. 4(b).

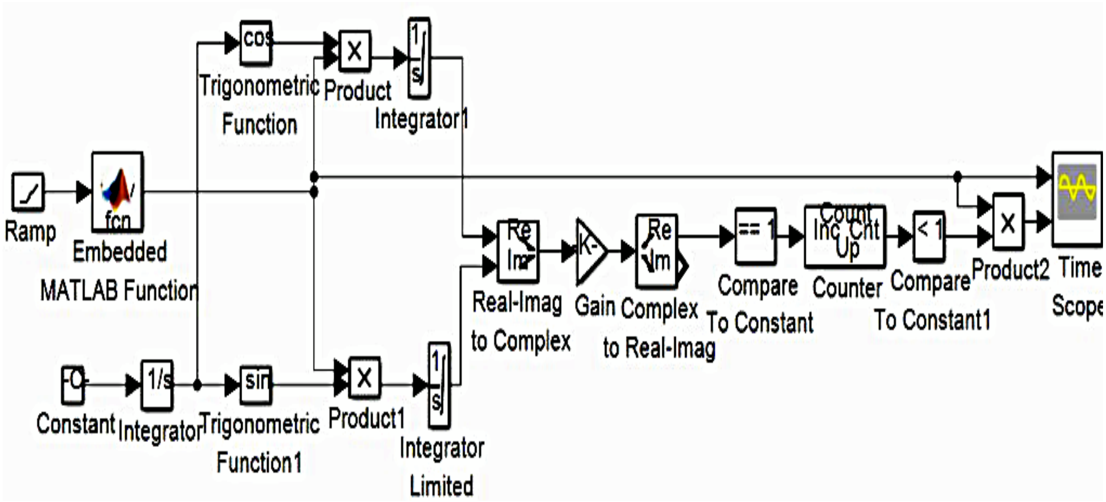

Fig. 2: Simulink model for Mains failure detection

3. RESULTS AND DISCUSSION

Result of the Fourier series based fundamental signal extraction shows harmonics affected Input signal and obtained harmonics free fundamental frequency signal in Figure. 3 (a) and (b).

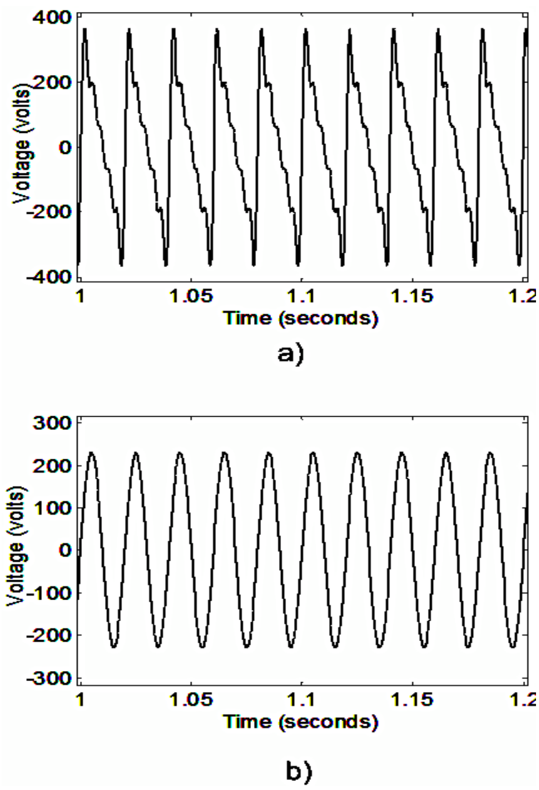

Fig. 3: Fundamental signal extraction by Fourier series a) Input signal with harmonics b) Extracted Fundamental signal.

Input harmonics are considered up to 5th harmonic with total harmonic distortion of 68.09%. The output reveals low harmonic distortion with 0.007%. First, second, third, fourth and fifth harmonics at input are 69.6dBm, 63.2dBm, 59dBm, 57dBm and 55.5dBm respectively. The output harmonics are 52.3dBm, -32.9dBm, -38.2dBm, -41.1dBm and -42.4dBm respectively.

Simulated result of mains failure detection using Fourier series is shown in Figure. 4 (a) and (b). From Figure. 4(a), It is observed that the 50Hz sinusoidal waveform exponentially decay when mains fail to become zero. This exponential decay depends on RC time constant and voltage of the capacitor. Due to delay in discharge of the voltage, detection time taken will be high. Figure. 4(b) shows detection of mains failure and voltage becomes zero at 3ms.

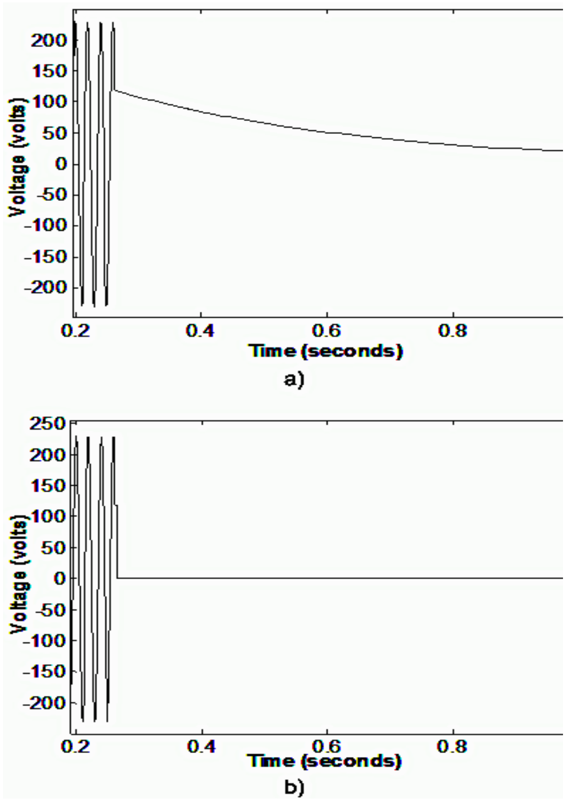

Fig. 4: Fourier series based mains failure detection. a)Input mains failure signal b)Detection of mains failure.

The time taken to detect mains failure by Fourier series method is dependent on instant of time failure. Failure is checked twice per cycle of input signal resulting in detection time less than 10 ms. In Figure. 4 (a) shows Mains failure at 0.262 sec and fall exponentially upto the measured period whereas, by implementing Fourier series method to the system the mains failure at 0.262 sec and the mains failure detector detects at 0.265 sec (i.e. the detection time is 0.003sec) was observed in Figure. 4(b). It clearly indicates that the Fourier series method will reduce the time taken to detect the mains failure. The experiment was repeated for mains failure at different instant of time and the results are tabulated in Table 1 for better understanding and conformity.

Table 1. Detection time of mains failure at different instant of time

Instant of Mains failure (ms)	Mains Failure detected at time (ms)	Required time for detection (ms)
52	55	3
56	65	9
60	65	5
65	65	0

4. CONCLUSION

The investigation is clearly demonstrated for the purpose of detecting power failures truly harmful to computer and medical application system in their earliest stage. Single phase AC mains failure detection was simulated with MATLAB/SIMULINK using Fourier series method. Fundamental signal extraction with Fourier series method reduced the input harmonics and time taken to detect the mains failure by Fourier series is less than 10 ms.

As a future scope, discrete time Fourier transform can be used to achieve real time and faster detection. The mains failure detection method can be explored to other systems such as implementation in grid synchronisation of distributed generator to avoid islanding, by shutting down the distributed generator on grid failure. It can also be implemented to detect voltage fluctuation.

5. ACKNOWLEDGMENTS

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