Simpson's rule digital LPF design for harmonic current filtering

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ABSTRACT: This paper presents a low-pass filter (LPF) design based on Simpson's rule numerical integrator and its application in filtering harmonic current. Conventional Butterworth LPF suffers from slow dynamic response and inherits large ripple signal. Using MATLAB Simulink tool, a current harmonic is filtered by the aforementioned LPFs and the resultant outcomes show that the Simpson's rule LPF is superior than the Butterworth LPF in term of ripple and dynamic response characteristics.

Keywords: *Simpson's rule; Harmonic current; Low-pass filter*

1. INTRODUCTION

Harmonic current filtering technique is essential for separating fundamental component from harmonic component of the distorted AC current waveform [1]. Usually, a low-pass filter (LPF) is implemented to extract the fundamental component from the distorted input signal. The LPF allows a signal with frequency lower than its stipulated cut-off frequency, f_c but attenuates the signals whose frequency is higher than the f_c. Besides, using the digital LPF will obtain an average value signal via numerical integration (averaging) method. Recently, the digital LPF is widely utilized and recommended due to its advantage to avoid direct approximations of system signal derivatives from sampled data [2]. Typical LPF in [1] is based on the conventional first order LPF, has caused its output signal suffers from slow dynamic response and significant ripple. Mainly because a time delay is present due to roll-off rate response. Thus, this will result in ineffective harmonic filtering process as well as leading to significant loss in the filtering circuit.

To overcome the drawbacks, a fast dynamic response LPF utilizing numerical integration method or digital integrator with good filtering characteristics is proposed. In general, the design methods of digital integrator can be classified into two categories which are comprised of infinite impulse response (IIR) filters and finite impulse response (FIR) filters respectively. Since the primary advantage of IIR filters over FIR filters is they typically meet their specifications with a much lower filter order. In fact, they are usually derived from classical analogue filters such as Butterworth, Chebyshev etc. Usually, the IIR filter coefficients are obtained directly from the well-known rectangular, Butterworth, Simpson's rule etc. methods [3]. Thus, the Simpson's rule method is selected as the main digital LPF for this work. This method was accurate when it was applied in Discrete Fourier Transform (DFT) to approximate the Fourier integral. Moreover, it was also applied as a fractional equivalent based on quadratic interpolation. This approach leads to improved rate of convergence for an approximation [4]. Hence, to realize a performance comparison, a conventional Butterworth LPF [5], was also designed and simulated to investigate respective dynamic response performance comparison.

The objective of this paper is to design and implement Simpson's rule based LPF to filter out harmonic current. This paper is organized as follows: Section 2 will introduce and discuss briefly about the methodology to generate harmonic current and to filter its distorted signal respectively. Circuit modelling and simulation depends on computer assisted simulation software, MATLAB Simulink tool. In Section 3, the simulation results will be presented and analysed, and finally in Section 4 will conclude this work.

2. METHODOLOGY

Figure 1 shows the overview of the input and output of basic LPF design. On the other hand, Table 1 indicates the circuit parameters used in the simulation.

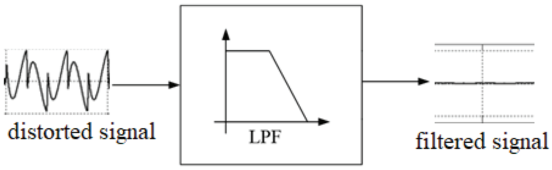

Figure 1. Overview of LPF

Table 1 Harmonic generator circuit parameter

Parameters	Value
Supply voltage, $V_{g,rms}$	36 V
System frequency, f	50 Hz
Load resistance, R_o	20 Ω
Load inductance, L_o	24 mH
Cut-off frequency, f_c	1 Hz
Sampling time, ΔT	5 µs

The harmonic current generator is made of a single-phase AC system connected to a nonlinear load comprising of a bridge diode rectifier circuit with inductive load. The nonlinear load draws the distorted non-sinusoidal waveform harmonic current. While the supply current, i_s phase angle lagging the phase angle of supply voltage, v_s. Thus, apart from a considerable high harmonic distortion (THD) content, it also effected the system power factor significantly less than unity.

With respect to the harmonic current filtering technique, the LPF design using Simpson's rule and Butterworth are introduced. Firstly, the harmonic current is sensed, and then its actual i_s signal is transformed into $|i_s|$ signal using an absolute operator. The purpose to change the AC signal into DC signal is to accommodate the signal as the input of LPF. After that, the $|i_s|$ signal is fed into the aforementioned LPFs to separate the fundamental component from the harmonic component. Hence, based on difference equation, the respective Simpson's rule LPF and the first order Butterworth LPF basic transfer functions [3], [5] can be expressed as:

$$\text{Butterworth:} \quad \frac{Y(z)}{X(z)} = \frac{a\left(1+z^{-1}\right)}{1+bz^{-1}} \tag{1}$$

$$\text{Simpson's rule:} \quad \frac{Y(z)}{X(z)} = \frac{\Delta T}{3}\frac{1+4z^{-1}+z^{-2}}{1-z^{-2}} \tag{2}$$

$$a = \frac{\pi f_C \Delta T - 1}{\pi f_C \Delta T + 1} \text{ and } b = \frac{\pi f_C \Delta T}{\pi f_C \Delta T + 1} \tag{3}$$

where $Y(z)$ and $X(z)$ are the input and output of the LPF in z-plane.

The MATLAB Simulink tool was applied to model and simulate the harmonic current generator as well as the harmonic distortion signal separator. The full system was simulated using a fixed step discrete solver and was set-up to run for 0.25 seconds. Among the desired simulation results are the THD of i_s and the dynamic response characteristics of LPFs output.

3. RESULTS AND DISCUSSION

Using the Fast Fourier Transform (FFT) analysis, the THD percentage of supply current is 18.35%. This indicates the harmonic content is sufficiently have larger amount than 5% THD recommended by IEEE 519 standard. The distorted waveform of i_s and its transformation signal, $|i_s|$ is depicted in Figure 2. The DC signal is fluctuating with a very high ripple value. Therefore, the LPF is implemented to filter out and smoothen the signal's fluctuation ripple.

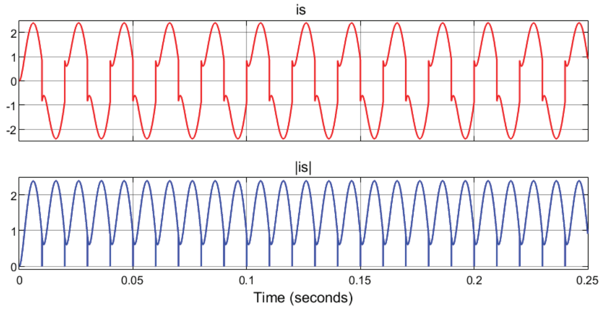

Figure 2. The i_s and $|i_s|$ waveforms

As expected, a perfect DC output signal should have a flattened straight line without any fluctuations so that it can reduce losses. Based on Figure 3, the Simpson's rule filter dynamic response is much better than the Butterworth filter. Table 2 shows the performance and dynamic response comparison of both LPFs, thus, many parameters is in favour of the Simpson's rule LPF.

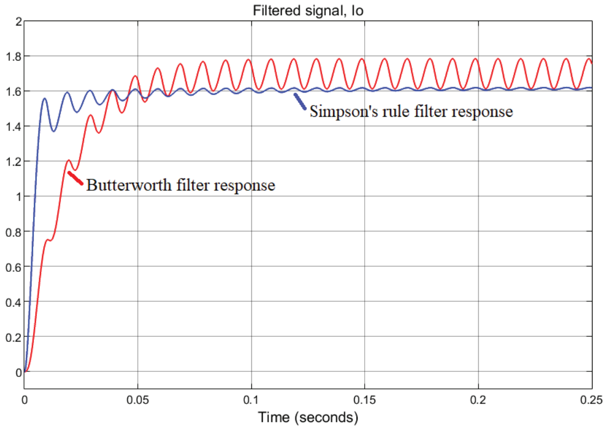

Figure 3. Dynamic response of the DC signal output

Table 2. Comparison performance

Performance	Simpson's rule	Butterworth
Rise time	Faster (0.01 s)	Slower (0.025 s)
%Overshoot	None	None
Settling time	Faster (0.015 s)	Slower (0.035 s)
Steady state error	Smaller	Larger
Stability	Yes	Yes
Ripple	Smaller	Larger

4. CONCLUSION

This work has achieved all the predetermined objectives. The Simpson's rule LPF turned out to be the best option as the harmonic separator with a faster dynamic response than the Butterworth LPF.

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