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FPGA based Implementation of Adaptive Notch Filter

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Abstract: *This paper presents the implementation of an adaptive notch filter (ANF) in field programmable gate arrays. Due to the nonlinear structure of the ANF, the implementation technique has a very high impact on the accuracy of the frequency estimation and the speed of convergence during transients. ANF is a powerful tool for grid synchronization. In this paper, ANF for harmonic signal extraction was simulated using VHDL and implemented in FPGA. It is widely used for harmonic and inter-harmonic extraction and elimination, amplitude, frequency and phase tracking and noise elimination. This is very useful in smart grids for power quality monitoring issues.*
Keywords: *Adaptive Notch Filter, Field Programmable Gate Array, VHDL*

I. Introduction

Grid-connected converters are an inevitable part of renewable energy generation systems. Grid-connected converters prepare deliverable power produced from various renewable energy sources such as wind, solar, etc. to the utility grid. Grid-synchronization is one of the essential components in any grid-conned power conditioning systems. Building a smarter and more distributed utility network requires the advancement of synchronization strategies.Grid-synchronization has been a very active area of research for a long time and a variety of phase detection techniques has been discussed in the literature [1]-[3]. Traditionally phase detection through zero crossings has been used for grid-connected converters. However, since zero crossings happen every half cycle, the dynamic performance of this technique is very slow. Also, this technique is not able to provide a reliable performance when the waveform is distorted. Filtering on dq-synchronous rotating frame or $\alpha\beta$ stationary frame is another common technique for grid synchronization. In this technique, filtering introduces delay into the estimation loop. This delay leads to a sluggish transient response of the frequency estimation and may result in instability in severe transients.

II. Frequency Estimation Through ANF

A synchronization method should have the ability to detect and track the phase information of the utility network in the presence of harmonics and disturbances. ANF based technique excels in areas where zero-crossing detection, filtering or PLLs fall short. The ANF was originally introduced and developed in different papers for different applications. The ANF structure on its own is able to provide a smooth frequency detection as well as magnitude estimation without introducing any delay into the estimation loop. It can be combined with pre- and post-filtering strategies to improve noise rejection and deliver smoother frequency estimation without much delay. Several papers have proposed techniques to mitigate the effect of DC-bias, the sensitivity to signal amplitude and improve the estimation performance when faced with distorted signals. However, there has not been much research on the practical aspects of the ANF digital implementations. This paper intends to focus on the practical aspects of the ANF implementation on a field-programmable gate array (FPGA) device. The analytical study and experimental results offer the optimized digital implementation approach for ANF implementation and provide a practical insight into ANF VHDL code.

A globally convergent frequency estimator is based on the adaptive notch filter in order to determine the frequency of a sinusoidal signal given by:

$$y = A_1 \sin(\omega t) \quad (1)$$

The ANF-based frequency estimator is a system governed by the following dynamics:

$$\ddot{x} + 2\varsigma\hat{\theta}\dot{x} + \hat{\theta}^2 x = \hat{\theta}^2 y \quad (2)$$

$$\dot{\hat{\theta}} = \gamma x(2\zeta\dot{x} - \hat{\theta}y)x\hat{\theta}$$

This is the modified version of Regalia's ANF (in continuous form) given by:

$$\ddot{x} + 2\varsigma\hat{\theta}\dot{x} + \hat{\theta}^2 x = y \quad (3)$$

$$\dot{\hat{\theta}} = \gamma x(2\zeta\hat{\theta}\dot{x} - y)$$

The modified version has better stability performance for convergence of x for low frequencies and provides a faster convergence for high frequencies.

III. Simulation Results

The harmonic signals estimation block has been implemented in Altera Cyclone II 2C20 FPGA using Hardware Description Language (VHDL). Fig. 1(a) shows the cascaded combination of four different frequency sinusoidal signals, which has been extracted as individual frequency signals by ANF. A portion of Fig. 1(a) is zoomed and shown in Fig. 1(b). Fig. 2 shows the individual frequency signals extraction from a modulated signal. Fig. 3 shows the individual frequency signals extracted from a signal, which is the combination of different frequency signals.

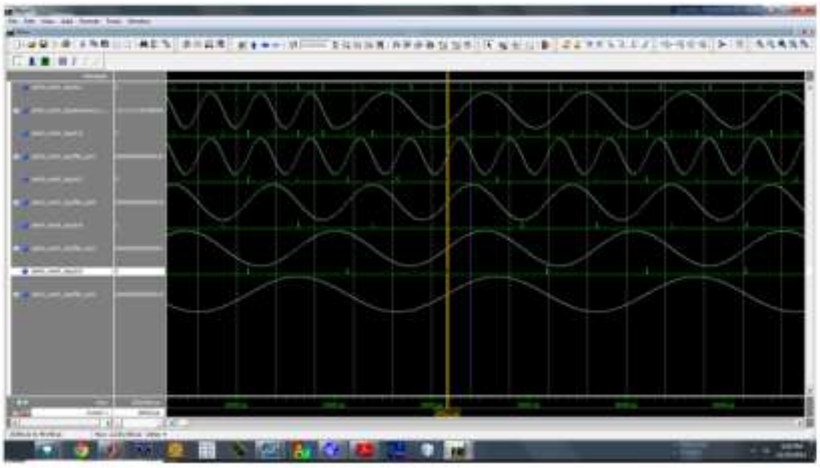

Fig. 1 (a) Harmonic signal extraction from a multiple frequency signal in cascaded form

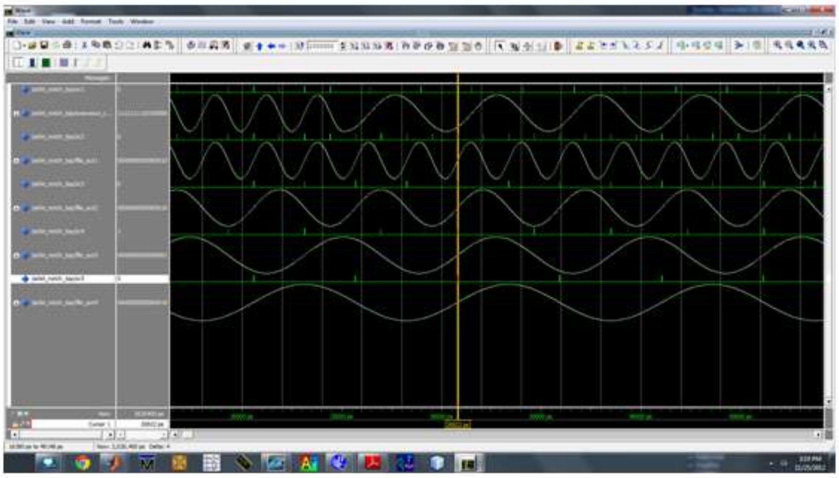

Fig. 1(b) A portion of Fig. 1(a) is zoomed

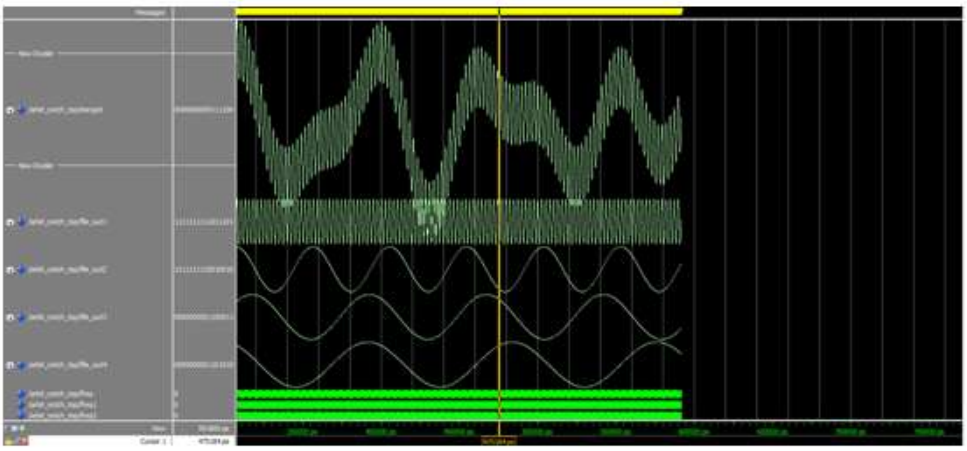

Fig. 2 Harmonic signal extraction from a modulated signal

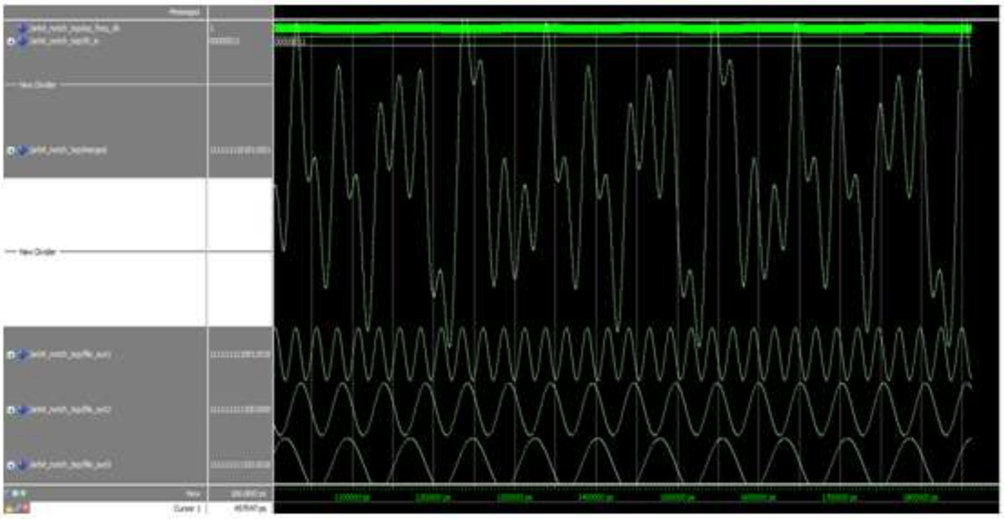

Fig. 3 Harmonic signal extraction for a multiple frequency signals added up

IV. Conclusion

ANF is a powerful tool for grid synchronization. In this paper, ANF for harmonic signal extraction was simulated using VHDL and implemented in FPGA. It is widely used for harmonic and inter-harmonic extraction and elimination, amplitude, frequency and phase tracking and noise elimination. This is very useful in smart grids for power quality monitoring issues.

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