

# SELECTIVE HARMONICS REDUCTION FOR PHASE LOCK LOOP UTILITY APPLICATION

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**Abstract-** The analysis and design of the phase-locked loop (PLL) system is presented for the phase tracking system of the single phase utility interface inverters. Phase-locked loops (PLL) are widely used in power electronics equipment connected to the mains. The use of a square wave voltage-controlled oscillator instead of a sinusoidal one eliminates one multiplier, resulting in a simple PLL algorithm, suitable for low-cost processors. In spite of its simplicity, distorted grid voltages cause steady-state phase error. This project proposes the use of a modified square waveform obtained by the selective harmonics elimination (SHE) method to solve the phase error problem.

**Key words:** *selective harmonics elimination (SHE), phase-lock loop (PLL), power electronics*

## 1. Introduction

Coincides with invention of “coherent communication” (DeBellecize, 1932). The earliest widespread use of PLLs to the horizontal and vertical sweeps used in television, where a continuous clocking signal had to be synchronized with a periodic synch pulse (Wendt & Fredendall, 1943). PLLs critical to development of colour television (Richman, 1954). The first PLL IC arrived around 1965. This created an explosion in the use of PLLs. The first digital PLL appeared around 1970. This was of the classical digital PLL type. A few years later, the first all digital PLL appeared. The first laser appears in 1960. The first optical PLL arrives 4 years later. PLLs today:

- PLLs in every cell phone, television, radio, pager, computer, all telephony.
- The most prolific feedback system built by engineers.
- At low end: all software PLLs implement entire PLL functionality on sampled data.
- At high end: optical PLLs used in clock recovery for 160 Gbps data (OFC 2002).
- Boy band called: N’Sync

Phase-locked loop (PLL) is a feedback loop which locks two waveforms with same frequency but shifted in phase. The fundamental use of this loop is in comparing frequencies of two waveforms and then adjusting the frequency of the waveform in the loop to equal the input waveform frequency. A block diagram of the PLL is shown in Figure 1. The heart of the PLL is a phase comparator which along with a voltage controlled oscillator (VCO), a filter and an amplifier forms the loop. If the two frequencies are different the output of the phase comparator varies and changes the input to the VCO to make its output frequency equal to the input waveform frequency. The locking of the two frequencies is a nonlinear process but linear approximation can be used to analyze PLL dynamics.

Phase lock loops (PLLs) belong to a larger set of regulation systems. As an independent research and design field it started in the 1950s

The task of the PLLs is to maintain coherence between the input (reference) signal frequency,  $f_i$ , and the respective output frequency,  $f_o$ , via phase comparison. Another feature of PLLs is the filtering property, particularly with respect to the noise where its behavior recalls a very narrow low-pass arrangement that is not to be realized by other means.

Each PLL system is composed of four basic parts:

1. The reference generator (RG)
2. The phase detector (PD)
3. The low-pass filter  $FL(f)$  (in higher-order systems)
4. The voltage-controlled oscillator (VCO) and works as a feedback system shown in Fig. 1

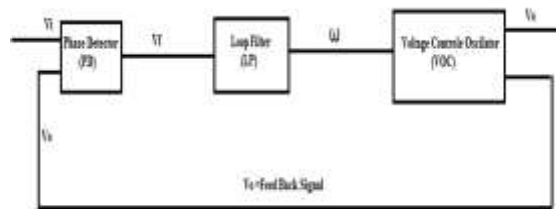


Fig1: Block diagram of PLL

Phase-locked loops (PLLs) are widely used in communication, control, automation, and instrumentation systems to achieve signal synchronization.

PLLs have found many applications in grid-connected power electronic devices:

- 1) To synchronize thyristor firing circuits.
- 2) To transform variables between stationary and synchronous rotating reference frames.
- 3) To compute power system disturbances in power quality monitoring systems.
- 4) To calculate reference signals for the internal control loops in uninterruptible power supplies dynamic voltage restorer's active filters and power converters used in distributed energy systems including wind and photovoltaic systems.

In these applications, the PLL detects the phase angle and frequency of the grid fundamental voltage. On the other hand, three-phase PLLs detect the positive sequence component, even for distorted and unbalanced grids.

## 2. SHE-PLL

Here we discuss about the SHE-PLL, if  $V_i$  and  $V_{os}$  have harmonics of the same order, they contribute to the dc component of  $v_{mult}$  resulting in phase error. One solution for this problem consists of eliminating all the relevant harmonics that exist in the input voltage  $V_i$  from the VCO signal  $V_{os}$ . This new signal is called  $V_{oSHE}$  and is obtained by means of the SHE algorithm.

The SHE waveform  $v_{oSHE}$  is shown in Fig. 2, for  $N = 5$  switching angles ( $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ ) per quarter of VCO period  $T$ . The remaining switching instants are calculated by using the quarter- and half-wave symmetry of  $v_{oSHE}$  shown in Fig3.3

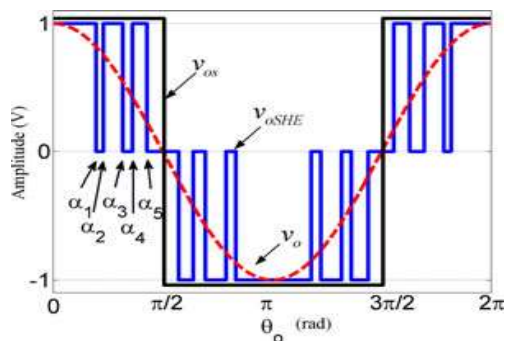


Fig 2; SHE proposed feedback signal, for N=5

The SHE waveform can be represented by a Fourier series according to

$$v_{oSHE} = \frac{a_0}{2} + \sum_{n=1}^{\infty} a_n \cos(n\omega_0 t) + b_n \sin(n\omega_0 t) \quad (1)$$

For the three-level  $v_{oSHE}$  waveform in Fig. 2, see the following.

1) The half-wave symmetry property results in  $a_0 = 0$ : The quarter-wave symmetry property results in

$$a_n = \begin{cases} \frac{8}{T} \cdot \int_0^{T/4} v_{oSHE} \cos n\omega_0 t dt, & n \text{ is odd} \\ 0, & n \text{ is even.} \end{cases} \quad (2)$$

2) The even-wave symmetry property of  $v_{oSHE}$  results in  $b_n = 0$  for all  $n$ :

According to [25], the quarter-wave coefficients are determined by

$$a_n = \frac{8}{2\pi} \cdot \left[ \int_0^{\alpha_1} \cos n\theta_0 d\theta_0 + \int_{\alpha_2}^{\alpha_3} \cos n\theta_0 d\theta_0 + \int_{\alpha_4}^{\alpha_5} \cos n\theta_0 d\theta_0 \right] \quad (3)$$

$$a_n = \frac{4}{n\pi} \cdot (\sin n\alpha_1 - \sin n\alpha_2 + \sin n\alpha_3 - \sin n\alpha_4 + \sin n\alpha_5). \quad (4)$$

In this project, the values of ( $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ ) are calculated by imposing  $a_1 = 1$ , and  $a_3 = a_5 = a_7 = a_9 = 0$  in (11), resulting in

$$a_1 = \frac{4}{\pi} \cdot (\sin \alpha_1 - \sin \alpha_2 + \sin \alpha_3 - \sin \alpha_4 + \sin \alpha_5) = 1 \quad (4)$$

$$a_3 = \frac{4}{3\pi} \cdot (\sin 3\alpha_1 - \sin 3\alpha_2 + \sin 3\alpha_3 - \sin 3\alpha_4 + \sin 3\alpha_5) = 0 \quad (5)$$

$$a_5 = \frac{4}{5\pi} \cdot (\sin 5\alpha_1 - \sin 5\alpha_2 + \sin 5\alpha_3 - \sin 5\alpha_4 + \sin 5\alpha_5) = 0 \quad (6)$$

$$a_7 = \frac{4}{7\pi} \cdot (\sin 7\alpha_1 - \sin 7\alpha_2 + \sin 7\alpha_3 - \sin 7\alpha_4 + \sin 7\alpha_5) = 0 \quad (7)$$

$$a_9 = \frac{4}{9\pi} \cdot (\sin 9\alpha_1 - \sin 9\alpha_2 + \sin 9\alpha_3 - \sin 9\alpha_4 + \sin 9\alpha_5) = 0 \quad (8)$$

The numerical solution for the system of five nonlinear (4)–(8) is obtained using the Newton–Raphson method. The starting point for the algorithm is obtained using the method presented in, resulting in  $\alpha_1 = 25.58^\circ$ ,  $\alpha_2 = 28.48^\circ$ ,  $\alpha_3 = 48.49^\circ$ ,  $\alpha_4 = 58.87^\circ$ , and  $\alpha_5 = 69.65^\circ$ . The block diagram of the proposed SHE-PLL (see Fig.3) is similar to that of the square wave feedback. A slightly bigger lookup table compared to the square PLL is now required, since additional switching angles must be included. However, the SHE-PLL table will still be substantially smaller than what is required for generating a sinusoidal waveform.

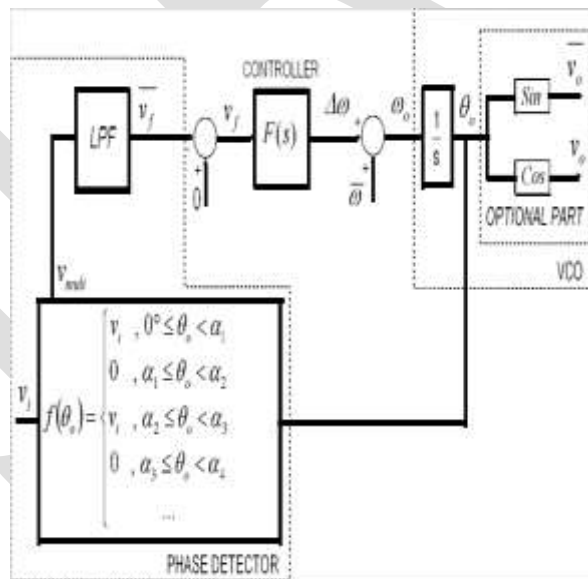


Fig3: Block Diagram of SHE-PLL Circuit of SHE-PLL

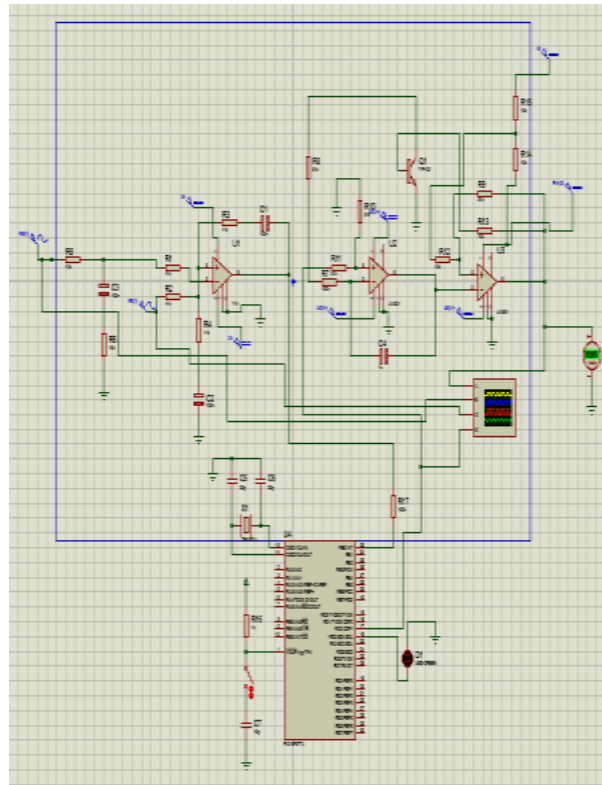
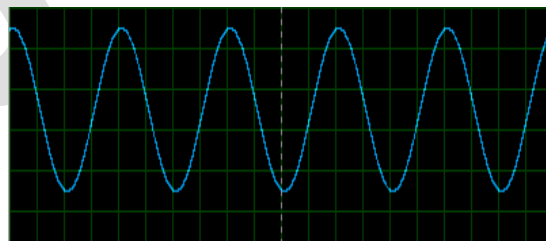


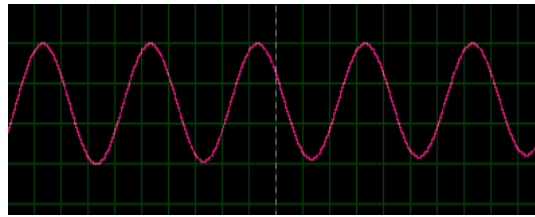
Fig4: Circuit of SHE-PLL

The fig4 shows the circuit of the SHE-PLL built using proteus software in the first part is the phase detector which detects the phase error of the two input signals and that is given to the controller here we are generating the pulse width modulated wave this width modulation was done by the values of the  $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$  the output of the controller is given to the VOC according to that we output signal VOC

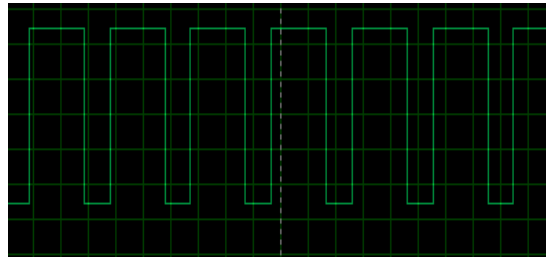
### 3. RESULTS



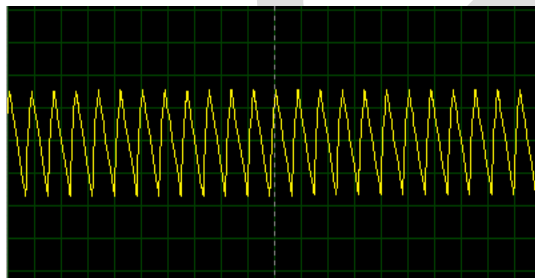
(a)



(b)



(c)



(d)

Fig 5: Simulation results : (a) input signal, (b) feedback signal, (c) SHE signal, (d) output of VCO.

#### 4. CONCLUSION

This paper presented an implementation of a single-phase PLL based on a square wave feedback signal with SHE, suitable for power system applications. The use of a squared wave VCO simplifies the implementation of PLLs in FPGAs, DSPs, or microcontrollers, because the number of multiplications is reduced and the sine and cosine calculations may be eliminated for some applications. The SHE-PLL also eliminates the steady state phase error inherent to the square wave PLL when the input signal contains harmonics.

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