Study and Simulation of Parks Transform PLL for robust single phase grid connected system

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Abstract—Grid synchronization algorithms are of great importance in control of grid connected power converter as fast and accurate detection of grid voltage parameters such as frequency, amplitude and phase is crucial in order to implement stable control strategies for the interconnection of grid with renewable energy such as DG systems. This paper gives the phase detection based on parks transform for single phase systems using quadrature delay. The matlab/simulink model for Q- PLL is presented.

***Keywords**-Q-PLL,grid connected power converter,single phase system,park transform,harmonic oscillator.*

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I. INTRODUCTION

The use of fossil fuels for electric power generation has imposed several problems on the environment including global warming and greenhouse effect. This has led to an era in which the increasing power demand will be met by Distributed Generation (DG) system which are based on renewable energy sources such as solar power, wind power, small hydro power etc. Among the green renewable energy sources, governments strongly support the application of wind energy and solar energy to power generation systems.

The DG systems are distributed near the user's facility. These systems are mainly small scale generations having capacity less than 20MW. These Distributed Generation (DG) systems need to be controlled properly in order to ensure sinusoidal current injection into the grid. However, they have a poor controllability due to their intermittent characteristics. Grid connected inverter is the key element to maintain voltage at the point of common coupling (PCC) constant and to ensure power quality improvements. For safe and reliable operation of power system based on DG system, usually power plant operators should satisfy the grid code requirements such as grid stability, fault ride through, power quality improvement, grid synchronization and power control etc. The major issue associated with DG system is their synchronization with utility voltage vector. The information about the phase angle of utility voltage vector is accurately tracked in order to control the flow of active and reactive power and to turn on and off power devices. For this reason, many phase locked-loop (PLL) control methods had been studied in the past decades[1].

The simplest method for phase detection is the zero crossing detection (ZCD)[2]-[4], where the zero-crossings are detected by capturing the rising or falling edges of the square-wave signals converted from input and output sine signals. To carry out phase control, the phase difference information is extracted. Although the zero-crossing-based PLL can easily be implemented, it fails when the synchronization signals have multizero-crossings resulting from harmonics or noises[3], and it has poor dynamic response due to one cycle or a half cycle control. So it requires a diverse approach to minimize phase detection errors from signals corrupted with noise and extraneous signals. Using pre-filtering and post processing can improve zero crossing detection [26]when combined with dynamic hysteresis or the interpolation method. The harmonics are effectively cancelled by the finite-impulse response filter, but the method needs an advanced microcontroller unit. For power system.

The cos function generates the quadrature signal, is the probably the easiest way to implement a quadrature signal generation[8]. It can be well programmed through the use of First-in-First-Out (FIFO) buffer, whose size is set to one-fourth of the number of samples contained in one cycle of the fundamental frequency. Three phase PLL mainly implement the synchronous reference frame method(p-q method)[10]-[15]. The p-q theory, in its original concept, is used in three-phase systems[16]-[23], but it is possible to implement it in single-phase systems by means of some modifications. However, fictitious two-phase orthogonal systems must be constructed based on the grid voltage when the p-q theory is used in a single-phase PLL.

The orthogonal signal generation and the p-q theory is implemented on the single phase system. The MATLAB model presented for the same method.

II. PHASE DETECTOR BASED ON QUADRATURE SIGNAL

A. Basic principle

The basic phase locked loop (PLL) concept was originally published by Appleton in 1923 and Bellescize in 1932, which was mainly used for synchronous reception of radio signals[25]. After that, PLL techniques were widely used in various industrial fields such as communication systems, motor control systems, induction heating power supplies and contactless power supplies.

Recently, PLL techniques have been used for synchronization between grid-interfaced converters and the utility network. An ideal PLL can provide the fast and accurate synchronization information with a high degree of immunity and insensitivity to disturbances, harmonics, unbalances, sags/swells, notches and other types of distortions in the input signal.

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The basic structure of a phase-locked loop (PLL) is shown in Figure. It consists of three fundamental blocks:

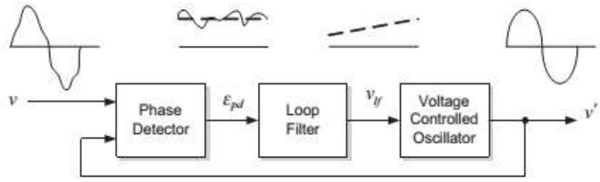


Fig1 Basic Structure of PLL

Phase Detector generates an output signal proportional to the phase difference between the input signal v, and the signal generated by the internal oscillator of the PLL v'. Depending on the type of PD, high-frequency AC components appear together with the DC phase-angle difference signal. Loop filter presents a low-pass filtering characteristic to attenuate the high-frequency AC components from the PD output. Typically, this block is constituted by a first-order low-pass filter or a PI controller. Voltage-controlled oscillator generates at its output an AC signal whose frequency is shifted with respect to a given central frequency ωc, as a function of the input voltage provided by the LF. Different techniques can be used to implement each blocks constituting a PLL.

B. Structure of PLL based on QSG and Parks Transform

Fig2 shows a PD based on a set of in-quadrature signals[28]. The quadrature signal generator (QSG) of this figure is supposed to be ideal, being able to extract a clean set of in-quadrature signals without introducing any delay at any frequency from a given distorted input signal.

The phase-angle error signal resulting from this ideal in-quadrature PD is given by

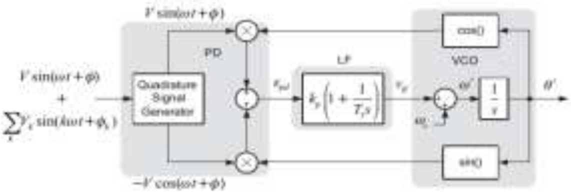


Fig2 Diagram of PLL with an ideal in quadrature PD

$$\varepsilon_{pd} = V\sin(\omega t+\phi)\cos(\omega' t+\phi') - V\cos(\omega t+\phi)\sin(\omega' t+\phi')$$
$$= V\sin((\omega-\omega')t + (\phi-\phi')) = V\sin(\theta-\theta') \qquad (1.1)$$

where an ideal sinusoidal signal, v_i=VmSin(ɵ)=VmSin(wt+ø), where Vm, ɵ ,w, ø are the amplitude, angle, frequency and phase angle of the input signal, it can be taken as "$_{\alpha}$" component of "αβ" systems, the 'β' component can be obtained by introducing a phase shift of π/2 rad with respect to fundamental frequency of input signal.

According to this equation, when the PLL is well synchronized, i.e. with ω=ω, the in quadrature PD does not generate any steady-state oscillatory term, which allows the PLL bandwidth to increase and overcomes discrepancies regarding calculation of the PLL key parameters.

A review of the above trigonometric expression reveals that this is a part of the Park transformation. Therefore, the above diagram can be redrawn as shown in Figure below, where the αβ to dq transformation block responds to the following transformation matrix:

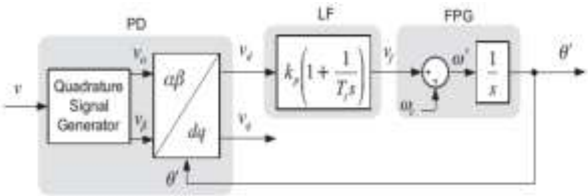


Fig3PD based on the quadrature signal generation and park transform

PD based on the quadrature signal generator and the Park transformation[27].

$$\begin{bmatrix} V^s d \\ V^s q \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} \qquad (1.2)$$

Where

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = \begin{bmatrix} \sin\theta \\ -\cos\theta \end{bmatrix} [V] \qquad (1.3)$$

The corresponding vector representation is shown in the fig. below where θ is t

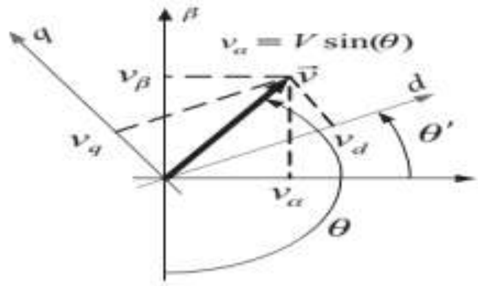


Fig4 Vector representation of the QSG output signals.

For rotating vector representation and related equations are:-

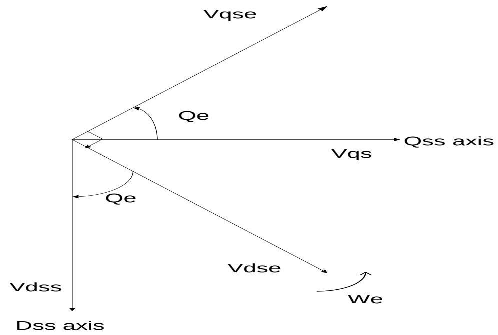


Fig5Stationary fram dq to synchronous rotating frame dq

$$V^e d = V^s q \sin\theta + V^s d \cos\theta \qquad (1.4)$$
$$V^e q = V^s q \cos\theta - V^s d \sin\theta \qquad (1.5)$$

C. Harmonic oscillator.

The sine and cosine waveform can be generated by the differential equation of an oscillator, is given by

$$\frac{d^2x}{dt^2} = -w^2 x \qquad (1.6)$$

Where 'x' is a function that is changing with time and w is the angular frequency in rad/sec (w=2πF).

Any differential terms in general can also be written as

$$\frac{dy}{dt} = y \quad (1.7)$$

$$\frac{d^2y}{dt^2} = y \quad (1.8)$$

Therefore the above equation of oscillator can be written as

$$\ddot{x} = -w^2 x \quad (1.9)$$

This is a second ordere differential equation.Consider one more 'y'that is chainging with time such that

$$y = \frac{1}{w}\dot{x} \quad (2.0)$$

This second order equation of oscillator (eq 1.9) can be converted into first order equation by substituting the derivative of eq2.0 in eq1.9. The derivative of eq2.0 is

$$\dot{y} = \frac{1}{w}\ddot{x} \quad (2.1)$$

Substituting in eq1.9

$$\dot{y} = -w\dot{x} \quad (2.2)$$

Eq2.0 and eq2.2 can be written in matrix for as

$$\begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} = \begin{bmatrix} 0 & w \\ -w & 0 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \quad (2.3)$$

The eigen values of eq 2.3 is given by

$$|sI - A| = 0 \quad (2.4)$$

$$s = \pm jw \quad (2.5)$$

The presence of only imaginary term 'jw' in eigen value (eq2.5) indicates that the response of system given by 2.3 is fully oscillatory and oscillating at w rad/sec. The solution of such response in time frame is

$$x = \sin wt$$
$$y = \cos wt$$

Thus x and y are actually the sine and cosine function of time frame. These two function can be simulated by using eq 2.4

$$\dot{x} = wy$$
$$\dot{y} = -wx$$

This is shown in fig6 below

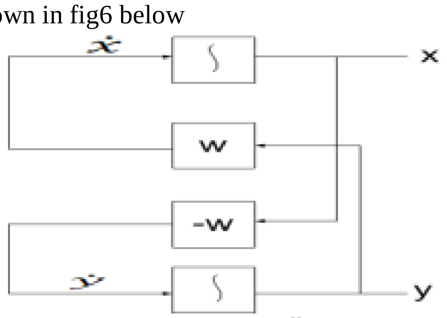
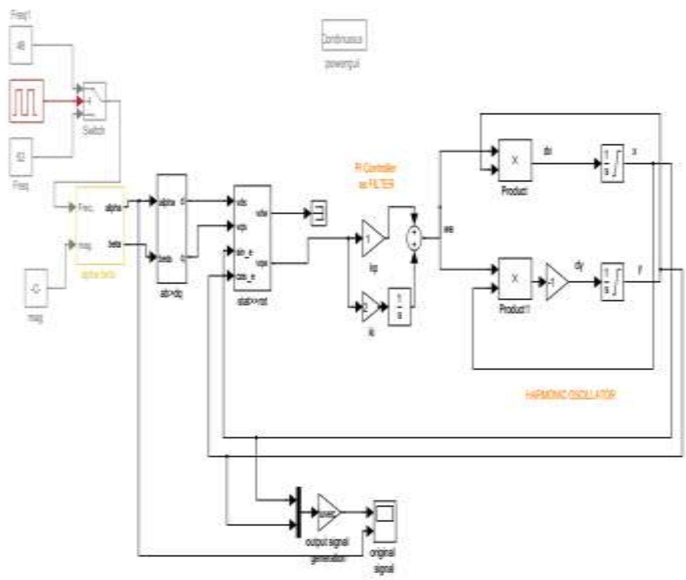


Fig 6 Harmonic oscillator

D. Simulation Results.

The simulation done in MATLAB/SIMULINK in that the two frequency component are used for analysis purpose.



Second frequency component comes after 10sec. The parameters of PI controller are most vital since changing any one parameter loose the synchronization. The oscillator oscillates the waveform at the frequency 'w' which is our input frequency. The output gain block is used for increasing the magnitude for comparison of the input and output signal.

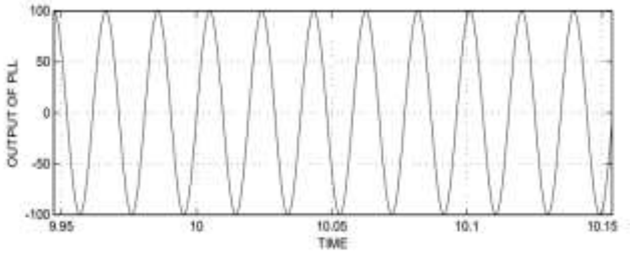


Fig 7 Output of PLL

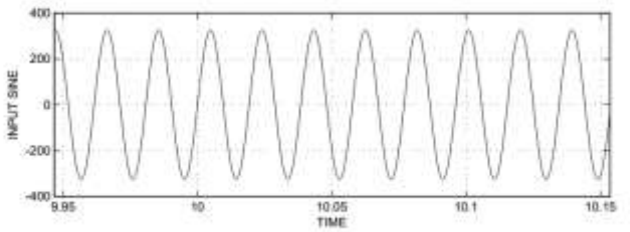


Fig 8 Input sine wave

III. CONCLUSION

The study of Q-PLL is done in the paper where the input is tracked by the PLL. In simulation the input tracking is done in 0.2 sec. The two frequencies are used in the simulation where second frequency starts after 10 sec of simulation. The related waveform are shown in the result

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