Performance Analysis of DSOGI PLL under Balanced and Unbalanced Conditions

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

in

Electrical Engineering

By

ARTHAM DIVYA

Roll No: 213EE5341

Department of Electrical Engineering

National Institute of Technology, Rourkela

Rourkela-769008, Odisha,India.

May 2015

Performance Analysis of DSOGI PLL under Balanced and Unbalanced Conditions

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

in

Electrical Engineering

By

ARTHAM DIVYA

Roll No: 213EE5341

Under the guidance of

Dr.S.GOPALA KRISHNA

Department of Electrical Engineering

National Institute of Technology, Rourkela

Rourkela-769008, Odisha, India.

May 2015

Department of Electrical Engineering

National Institute of Technology, Rourkela

CERTIFICATE

This is to certify that the dissertation entitled **"PERFORMANCE ANALYSIS OF DSOGI PLL UNDER BALANCED AND UNBALANCED CONDITIONS"** being submitted by **Artham Divya (213ee5341)** in partial fulfillment of the requirements for the award of Master of Technology degree in **"ELECTRICAL ENGINEERING"** with specialization of "**INDUSTRIAL ELECTRONICS"** at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

Date:

Place:

Dr. S. GOPALAKRISHNA

Assistant professor

Department of Electrical Engineering

National Institute of Technology

Rourkela-769008

ACKNOWLEDGEMENT

I would like to thank my Guide **Dr. S. Gopalakrishna,** for his guidance and continuous encouragement which leads to successful completion of our project. Having the project with our guide for whole academic session it is indeed a great pleasure.

I am also thankful to our HOD, **Prof. A. K. Panda,** for giving valuable suggestions and guidance in completing the project successfully by providing all the facilities to complete our project successfully. I am grateful to **all the faculty members** of **EE** Department for their inspiring guidance and advice.

By

Artham Divya

ABSTRACT

DPGS (distributed power generation system) gives an efficient and economic way of generating electricity by using renewable energy sources near to the load requirement. And it is the better way for reducing the transmission and distribution losses. But the process of synchronizing the DPGS system with grid is becoming one new challenge. As a consequence, the control of grid-connected power converters, grid synchronization method are very important because in order to implement stable control strategies under generic grid conditions a accurate and fast detecting method of the grid voltage characteristics is required .In actual practice the grid code requirements such as grid stability fault ride through, power quality improvement, power control and grid synchronization etc. should be satisfied by power plant operators.

There are so many methods for grid synchronization , has been explained in the literature review to control the parameters like active and reactive power by tracking the phase angle of the supply grid voltage or grid current for proper synchronization of grid and DG system.

In this thesis different types of grid synchronization system with DPGS system has been explained and later different types of PLL has been introduced for single phase and 3 phase system. For balanced 3 phase supply for getting better result SRF PLL is advisable, it uses the advanced method of conversion to 2 constant voltages from 2 orthogonal signals known as Park's transform and the Clarke's transform, it will take 3 phase supply as input and gives the 2 orthogonal signals as the output. But whenever the supply voltage is unbalanced the SRF PLL gives the output with the oscillating error means it is going to fail, so in case of the unbalanced supply voltage Decoupled Double Synchronous Reference Frame (DDSRF) PLL is suggested .the DDSRF PLL can detect the sequence components and positive

sequence phase angle under unbalancing conditions. For generating the orthogonal signals Second Order Generalized Integrator (SOGI) is the better replacement of Clarke's transform and it has high capacity of harmonic rejection because it can perform current controller duty and also sequence components also can be detected easily. For grid synchronization another advanced method is Dual Second Order Generalized Integrator - Phase Locked Loop (PLL) has been implemented by using Matlab simulink and LABVIEW under unbalanced conditions like sag and swell.

LIST OF ABBREVIATION

DPGS	**Distributed Power Generating Station**
OSG	**Orthogonal Signal Generator**
PLL	**Phase Locked Loop**
PI	**Proportional and Integral**
SOGI	**Second Order Generalized Integrator**
ZCD	**Zero Crossing Detector**
NI	**National Instrument**
SRF	**Synchronous Reference Frame**
LabVIEW	**Laboratory Virtual Instrument Engineering Workbench**
USB	**Universal Serial Bus**
DSOGI	**Doubly Second Order Generalized Integrator**
DDSRF	**Decoupled Double Synchronous Reference Frame**

LIST OF SYMBOLS

V_α	**Alpha component of supply voltage**
V_β	**Beta component of supply voltage**
V_d	**Direct axis component of supply voltage after Park's transform**
V_q	**Quadrature axis component of supply voltage after Park's transform**
θ	**Phase angle of input voltage**
V_{abc}	**3 phase supply voltage**
V	**Single phase supply voltage**
ω	**Angular frequency of supply voltage**
$[T_{\alpha\beta}]$	**3 phase to alpha beta transformation matrix**
q	**Phase shift operator $1\angle{-90^\circ}$**
A	**amplitude of input supply voltage**

CONTENTS

Introduction

1.1 INTRODUCTION

The synchronisation of DPGS system with grid is of great importance and PLL is the main part for generating pulses for inverter from the current controller. The PI controller will give error for the sinusoidal control variables so it is better to use PLL inplace of that one.

1.2 MOTIVATION

In order to increase the electricity generation by using renewable energy sources and to improve the diversity of the grid and to reduce frequent system failures. As compared to large power generation systems the number of system failures or less in the DPGS system. For proper injection of current in to the grid the proper control of distributed generation (DG) systems is compulsory. To achieve the perfect electrical conditions like unity power factor, constant voltage etc the main is to compensate the negative sequence component and by using exact value of positive sequence component . So it is necessary to finding the sequence components. And phase angle of line voltage is the factor for controlling the function of active or reactive power and to modify the feedback variables in voltage monitoring grid synchronization system.

1.3 LITERATURE REVIEW

Earlier some of the grid synchronization methods used zero crossing detectors for finding the frequency and phase angle of the grid voltage. But for weak grid the power quality problems can easily disturb the performance of ZCDs. for the better response of grid synchronization system it is better to use Phase Locked Loop (PLL) [1]. In case of single phase supply linear PLL is useful for phase detection. SRF PLL gives better result for balanced 3 phase supply, it uses the conversion of 2 orthogonal signals in to 2 constant voltages known as Park's transform and the Clarke's transform is used to generate the 2 orthogonal signals from the 3 phase supply. But whenever the supply voltage is unbalanced the SRF PLL is going to fail [2], so for dealing with the unbalanced supply voltage Decoupled Double Synchronous Reference Frame (DDSRF) PLL is suggested [3].the DDSRF PLL can detect the positive and negative sequence components and positive sequence phase angle under unbalancing conditions. How the DDSRF PLL is synthesized is explained in [4] and it can be implemented very easily and it is frequency adaptive. The enhanced PLL for 3 phase system synchronizes each single phase independently and there is no need of synchronous reference frame [5].For generating the orthogonal signals Second Order Generalized Integrator (SOGI) is the better replacement of Clarke’s transform and it has high capacity of harmonic rejection because it can perform current controller duty [6] and also sequence components also can be detected easily. For grid synchronization another advanced method is Dual Second Order Generalized Integrator - Frequency Locked Loop (FLL) [7]-[8].DSOGI and MSOGI FLL can be used at more than one frequency [9].

1.4 THESIS OUTLINE

In **chapter 1**, abstract of the thesis and what is the motivation for this project and what literature review has been done is explained.

In **chapter 2** ,a brief introduction of the DPGS system and how it is synchronized with the utility grid, different types of grid synchronization methods, and different types of PLL , a detailed explanation of the SOGI-OSG and operation of the SOGI-OSG PLL and results of the single phase PLL in the Matlab simulink .

In **chapter 3**, Park's and Clarke's transform has been explained, sequence components & SRF PLL has been introduced and DSRF PLL and DSOGI PLL and it's results using the Matlab simulink has been explained.

In **chapter 4**, hardware implementation of the DSOGI PLL using LabVIEW and results for the balanced and unbalanced conditions like sag and swell has been explained.

In **chapter 5**, conclusions of this thesis and future scope of the project has been explained.

CHAPTER -2

Synchronization of DPGS system with Grid

2.1 INTRODUCTION

As the demand of electricity goes on increasing the size of Power plant goes on increasing and the number of synchronous generators connected to grid is increasing so that maintaining the stability of the grid is becoming very difficult. An electric grid is a network of synchronized power providers and consumers that are connected by transmission and distribution lines and operated by one or more control centres.

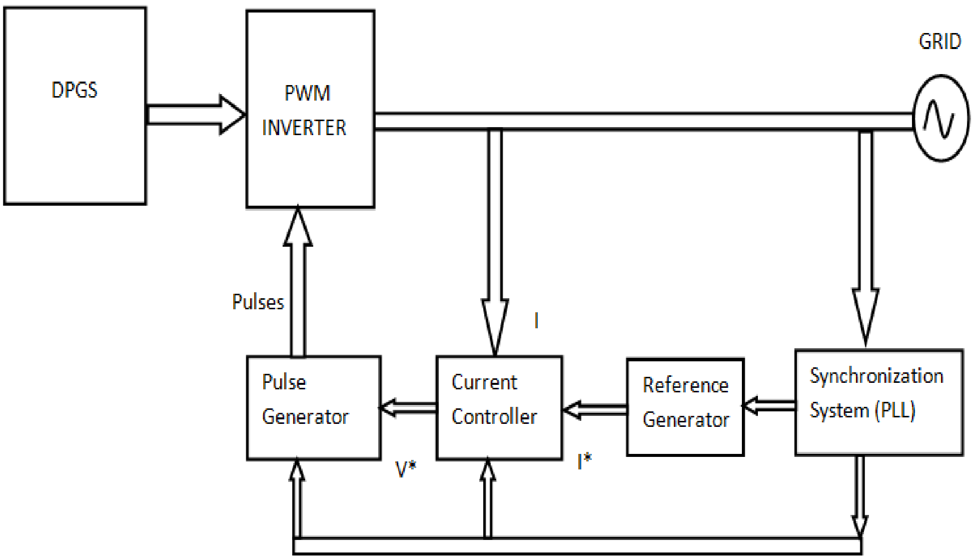


Figure.2.1. Block diagram of connection of DPGS with grid

DPGS (Distributed Power Generation System) units are small-scale generators which can be installed by end-users or private investors in the distribution network in order to meet their own demand. Used to generate electricity for homes, farms, business & industries. Examples of DPGS system is solar cell, wind generation system, fuel cells. DPGS system could act as self healing system that can quickly recover from failures. For proper grid operation the value of Grid Frequency is about according to the IEC61727-2002 50± 1 Hz and Voltage unbalance is 2% from nominal value [1].

Synchronization is a process of matching the characteristics (voltage and frequency and phase) of the DPGS system to the grid characteristics for exchange of power without losing its stability. When one (or) more components become desynchronized, part (or) the entire grid loses its stability and power outages can occur.

The DPGS system output is always dc and grid is AC operating system. So in order to synchronize two different systems here we are using PWM (Pulse Width Modulation) inverter to convert dc to ac signals as shown in Figure.2.1.The PLL will track the phase angle and frequency and magnitude of grid voltages and that will be given to the current reference generator from that we can control the pulses of the inverter so that the inverter output should match with the grid characteristics.

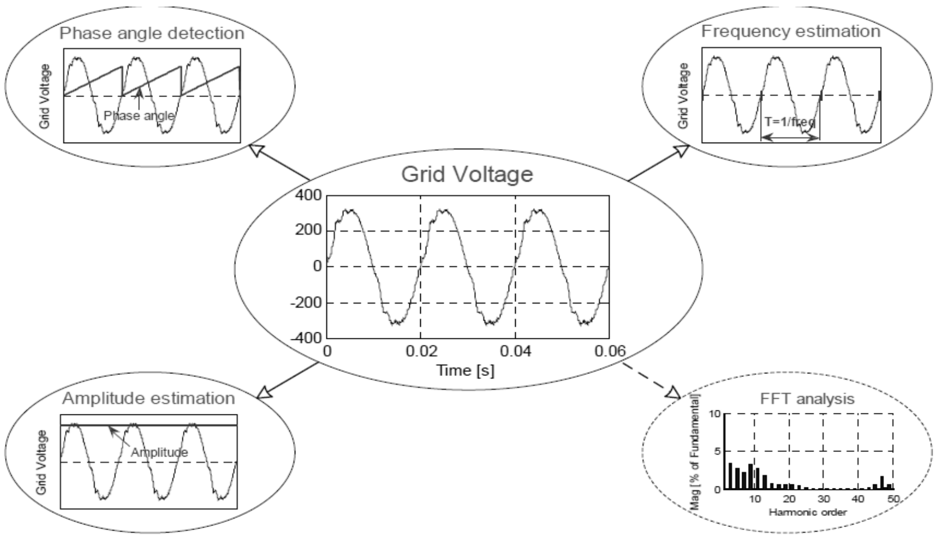
This work will show

- The response of Second Order Generalised Integrator-Orthogonal Signal Generator (SOGI-OSG) PLL for single phase system for the information about the phase angle of grid voltage vector.
- The study of DSOGI PLL and its response for finding the sequence components of grid voltage under balanced conditions in Mat lab simulink and under unbalanced condition (sag and swell) using Lab VIEW.

2.2 METHODS OF GRID SYNCHRONIZATION

The DPGS system can be synchronized with the grid by synchronizing the characteristics like frequency, phase angle and amplitude of grid voltage as shown in Figure.2.2 and by comparing any of these characteristics with the DPGS system voltage characteristics then the required reference signal can be generated for the pulse inputs for the DPGS side inverter can be generated. This can be achieved by using two methods

1) Zero Crossing Detector (ZCD) 2) Phase Locked Loop (PLL)



\

Figure 2.2. Voltage monitoring system [2]

2.2.1 ZCD BASED PLL

By finding the number of zero crossing points of the utility grid voltage it can be easily obtain the information regarding the frequency and phase angle of the grid voltage. Here by counting number of zero crossings the frequency can be estimated and by integrating the angular frequency of the voltage the phase angle can be tracked efficiently without using any phase controller as shown in Figure.2.3 here for every half cycle the zero crossing point is going to be detected but whenever the grid voltage having distortion like notches due to switching operation of power devices it will give wrong results. So for proper detection of frequency of grid voltage the fundamental components needed at the line frequency. To get the fundamental component filter has been needed and because of that delay is going introduces in the system. So whenever fast and accurate detection of grid parameters is needed it is not advisable method.

- T (time period) = twice the time gap between 2 zero crossings

- f (frequency in Hertz) = 1/T ,ϴ(phase angle in degrees) = ω.t

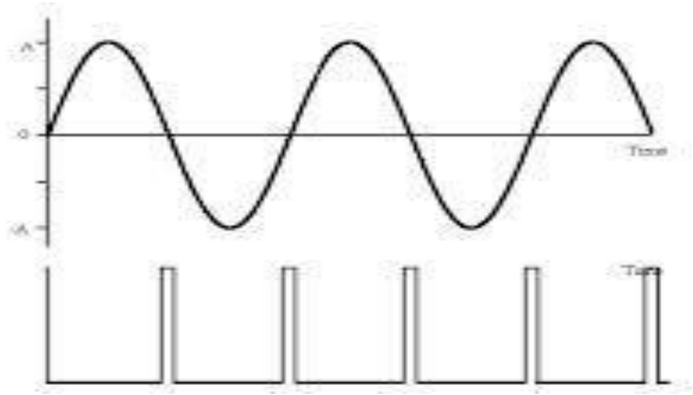


Figure 2.3. Working of ZCD [1]

2.2.2 PHASE LOCKED LOOP

Phase Locked Loop is a closed loop system which is used to synchronize the phase angle of the utility grid and DPGS system i.e., it will give the output as phase angle or frequency of the given input signal. For a sine wave signal how the phase angle is calculated is shown in Figure 2.4. And for 3 phase system the phase angle calculated for any one of the phase signal and to get the remaining phases phase angle +-120 degrees can be added. How the phase angle is varied for 3 phase system is shown in Figure.2.5. Here the phase angle is calculated in the range of 0 to 360 degrees. To convert -180 to 0 degrees range to 0 to 360 ranges add the 360 degrees to the signal phase as shown in Figure.2.6.

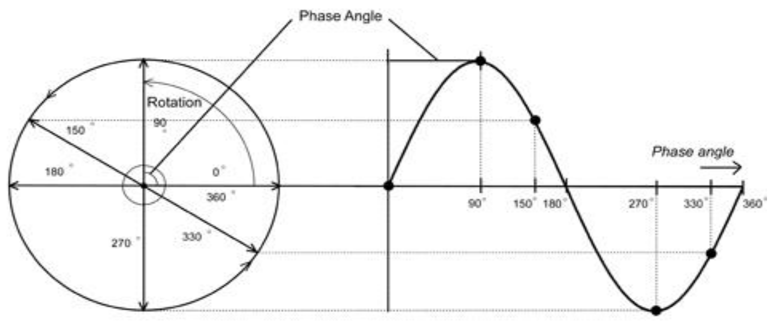


Figure 2.4. Phase angle calculation of sine wave signal [8]

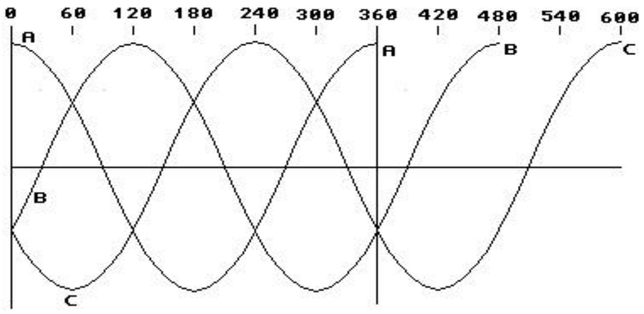


Figure 2.5. Phase angle calculation of 3 phase system [8]

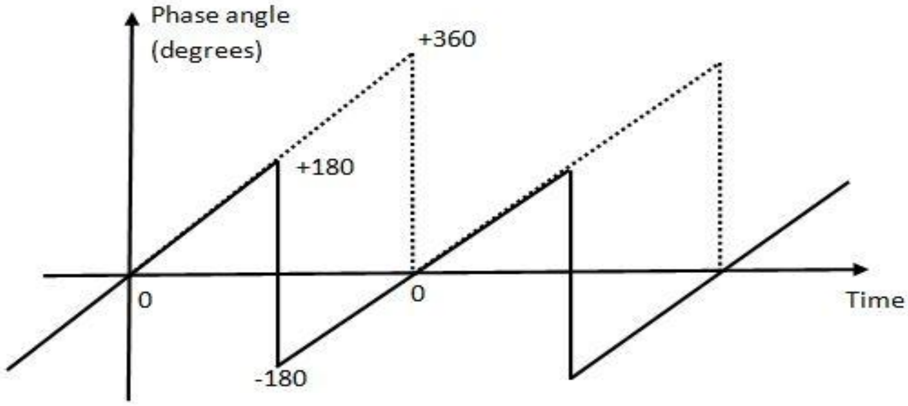


Figure 2.6. Conversion of +180 to -180 range to 0 to 360 range

2.2.3 TYPES OF PLL

There are different types of PLL as shown in Figure.2.7.in that Zero Crossing Detector(ZCD) based PLL track the frequency of the grid based on the number of zero crossings in a particular time but when the signals are distorted it will give the wrong results. Because of delay in the delay based PLL, it will take more time to track the phase angle. The arc tangent based PLL use the tan inverse function to find the phase angle but whenever the denominator becomes zero it will give wrong value. By using Clark's and park's transformation the three phase utility grid voltage has been transformed from natural reference frame to rotating reference frame in SRF PLL. By using feedback loop i.e., the reference frame's angular position we can make the positive sequence component's 'q' component to zero. Therefore the measured d-component gives the voltage vector magnitude, while its phase angle is tracked by using the feedback loop. The SRF PLL takes in a linearization assumption so the results can be guaranteed locally only. So the schemes which are based on the SRF PLL approach are sensitive to harmonic distortion. [1].

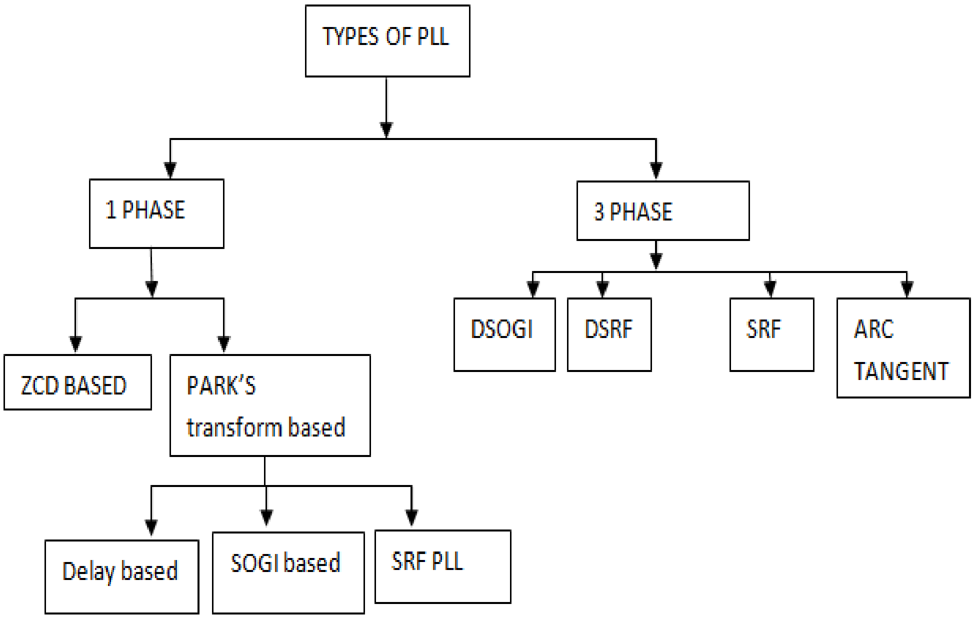


Figure 2.7. Types of PLL for single phase and 3 phase system

Advantages of OSG-SOGI based PLL:

- We can find sequence components of 3 phase system.
- Relatively simple to implement
- Robust under grid voltage disturbances
- The orthogonal system is filtered without delay
- Offset rejection capabilities
- Frequency adaptive

2.3. SOGI BASED ORTHOGONAL SIGNAL GENERATOR

The 2 signals can be defined as orthogonal signals when there is a phase difference of 90˚ between that 2 signals and those signals should be continuous and magnitude and frequency should be same. There are many methods for generating the orthogonal signal for a given signal. By delaying the given signal for 90˚ also we can get orthogonal signal but it will affect the performance of the system and by using the Hilbert transform also orthogonal signals can be generated but there is a introducing of the error.

For generating the orthogonal signals as shown in Fig.8.Second Order Generalized Integrator (SOGI) is the better replacement of Clarke's transform and it has high capacity of harmonic rejection because it can perform current controller duty and also sequence components also can be detected easily. By using SOGI based OSG the characteristics which can be avoided are high sensitivity to offset, high complexity so that chance of getting good dynamic performance and less sensitiveness to frequency variations can be achieved and it can be implemented very easily when compared to other osg techniques. It is a most advanced method resulting from adaptive kalman filtering theory. In previous for calculating active and reactive power instantaneous values this method has been used. From the literature review and based on performance it can decided that SOGI based OSG is the best method compared to other osg techniques.

In a 2 phase system for sequence component ,the quadrature signal takes an important role .By using OSG SOGI it not only does it help to generate quadrature signal but also it acts as a frequency adaptive band pass filter ,an integrator and also a small change in SOGI helps to find the frequency. So that here we prefer DSOGI PLL for grid synchronization and it will give better performance. Because of its selective nature of SOGI OSG it can suppress the utility voltage signal harmonic content.

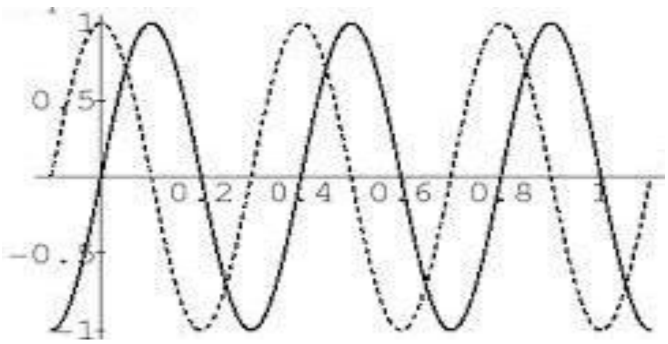


Figure 2.8. Output signal waveforms of OSG [3]

The basic concept of SOGI for sinusoidal signals was presented in [2]. At a selected resonant frequency the SOGI will introduce an infinite gain for avoiding steady state error [3]. It is robust under grid voltage disturbance, orthogonal signals will be generated without delay, it has offset rejection capabilities, it is frequency adaptive i.e., we can use it for any frequency [1]. The SOGI OSG is used to generate orthogonal signal of a given signal (V', q_V') having a phase shift of $\frac{\pi}{2}$ and V' has the same amplitude and phase as the fundamental of the applied voltage signal and it is relatively simple to implement as shown in Figure.2.9.

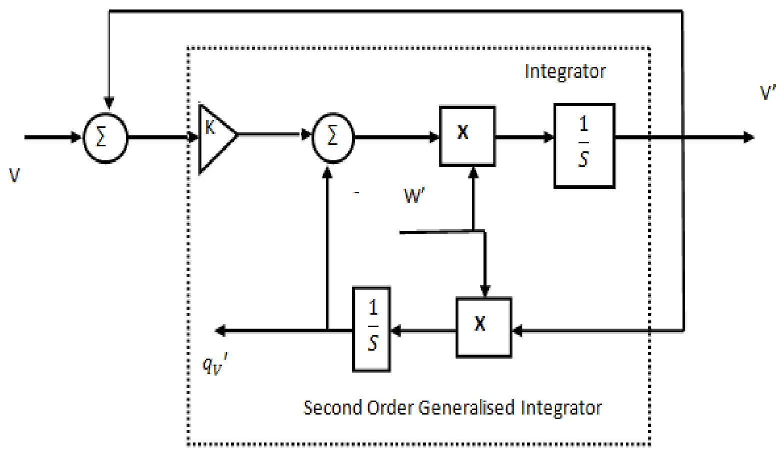


Figure 2.9. Block diagram of SOGI-OSG

The transfer function of the SOGI is given by [3] .

$$\frac{q_V'(s)}{V} = \frac{k\,\omega'^2}{s^2 + k\omega' s + \omega'^2} \qquad (2.1)$$

$$\frac{V'(S)}{V} = \frac{k\omega' S}{S^2 + k\omega' S + \omega'^2} \qquad (2.2)$$

Where ω' is the undamped natural frequency of the SOGI it is equal to the estimated grid frequency. Where k is the gain of the SOGI band pass filter and it will affect the bandwidth of the SOGI .The time response of the OSG-SOGI for a given sinusoidal input signal $V = V\,sin(\omega t + \emptyset)$ is given by

$$V^{'} = -\frac{V}{\lambda}\sin(\lambda\omega t)\ e^{\frac{kw'}{2}t} + V\sin(\omega t) \tag{2.3}$$

$$q_V^{'} = V[\cos(\lambda\omega t) + \frac{k}{2\lambda}\sin(\lambda\omega t)]e^{\frac{k\omega^{'}}{2}t} - V\cos(\omega t) \tag{2.4}$$

Here $\lambda = \sqrt{(4-k^2)}\,/2$ and k <2 (2.5)

$$t_s(SOGI) = \frac{10}{k\omega^{'}} \tag{2.6}$$

Where V' & q_V' are the outputs of SOGI OSG i.e., generated orthogonal signals respectively for single phase system. From the above equation of (2.6) it can be understood the settling time of the SOGI-OSG depends upon the gain of the system and it is inversely proportional. So in order to meet above specifications and less settling time the value of gain is selected as k=1.414. The output of OSG SOGI is shown in Figure.2.14.

2.4 OFFSET REJECTION USING OSG-SOGI

In the process like different data conversions like analog to digital or digital to analog processes or in the process of measurements there is a more chances of introducing voltage offset value and it is not advantageous for various aspects. The frequency of the error which is caused by the voltage offset in the system is very low because the voltage offset has the frequency same as the frequency of the grid voltage so it is very difficult to eliminate for the normal OSG techniques. In SOGI OSG the error signal is amplified by using the system gain value and then this error can be eliminated by using the band pass filtering action of the SOGI OSG and the amplification factor of the system is shown in the Figure.2.10.

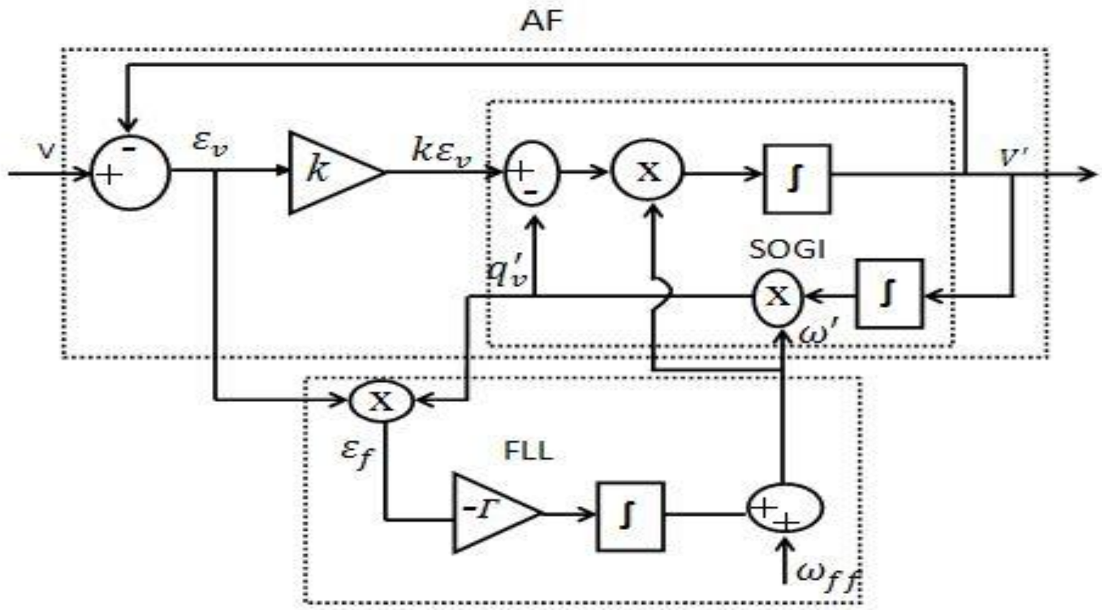


Figure 2.10. Block diagram of SOGI-OSG with offset rejection

2.5. SOGI –OSG BASED PLL

The PARK transform based PLL is most widely used. Here 2 orthogonal signals have been generated by using the SOGI-OSG. Here PI controller is used for making the steady state error to very less value nearly to zero and if it is minimum phase PI controller then is useful for the making the minimum phase error to zero value. After estimating the frequency, if it will integrate then grid voltage phase angle can be estimated as shown in Figure.2.11. For distortion free input signal, this PLL estimates the input phase angle without any double frequency ripple in the loop as shown in Figure.2.11.Single phase PLL suffers from the presence of second harmonic ripples when input is distorted . Here the two orthogonal signals have been equalled to the sine and cosine function and sine value of small angle can be equalled to that of angle value.

$$\varepsilon_\theta = V_q = -sin\theta'.cos\theta + cos\theta'.sin\theta \qquad (2.7)$$

$$= \sin(\theta - \theta') \approx \theta - \theta'$$

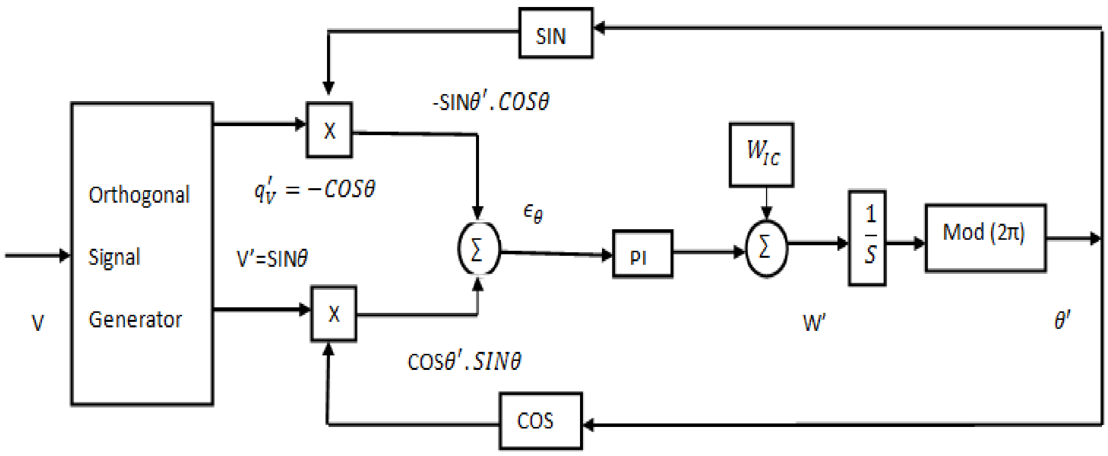


Figure 2.11. Block diagram of SOGI-OSG based PLL

Here ε_θ is the error value and is equalled the phase angle value and $\omega_{IC}$is the initial frequency of the utility grid and at starting it has to be fixed at some reasonable value and it depends upon the grid conditions and after integrating its value the angular frequency of the signal has been calculated and the error has been corrected by using the feedback loop so that exact value of phase of the signal can be achieved. The output signal waveforms of OSG SOGI based PLL has been shown in the Figure.2.14.where red colour signal is the input signal and black colour signal is the generated orthogonal signal. Here the mod function is used to limit the integrated frequency within the limits and the value of frequency of input signal tracked by using MATLAB simulink is 50 Hz is as shown in Figure.2.12. And the phase angle in radians as shown in Figure.2.13.

2.6 RESULTS OF SOGI-OSG PLL USING MATLAB SIMULINK

The results shown below is for the simulation time of 1 second and sampling rate of 1 kHz and the simulation type is continuous mode. The 2 orthogonal signals are settled within 0.1 seconds. And up to 0.1 seconds it is oscillating because of the integrator and feedback property. There is a small oscillation of very less magnitude in the detected frequency of around +-0.1 Hz and it is very negligible. From the below results it can be understood that SOGI OSG is the better choice for the generation of orthogonal signals and those are in equal magnitude and 90˚ phase displacement is there.

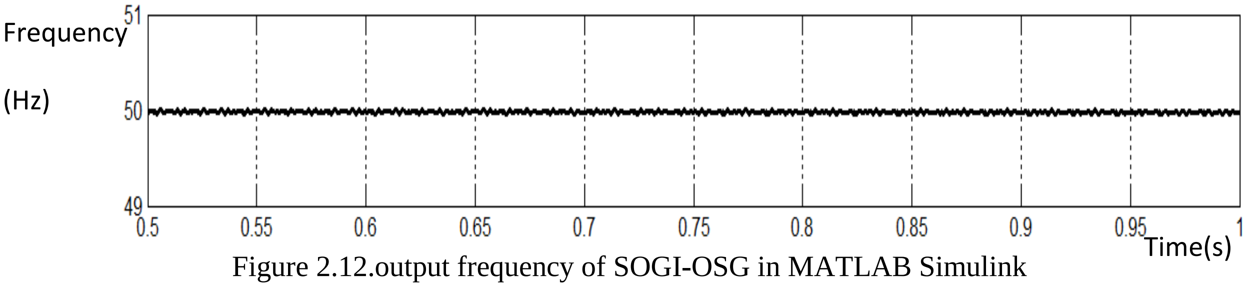


Figure 2.12.output frequency of SOGI-OSG in MATLAB Simulink

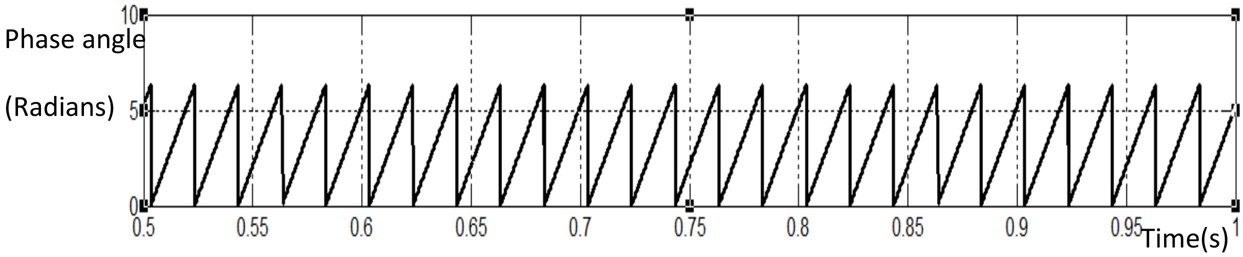


Figure 2.13. Output phase angle of SOGI-OSG in MATLAB Simulink

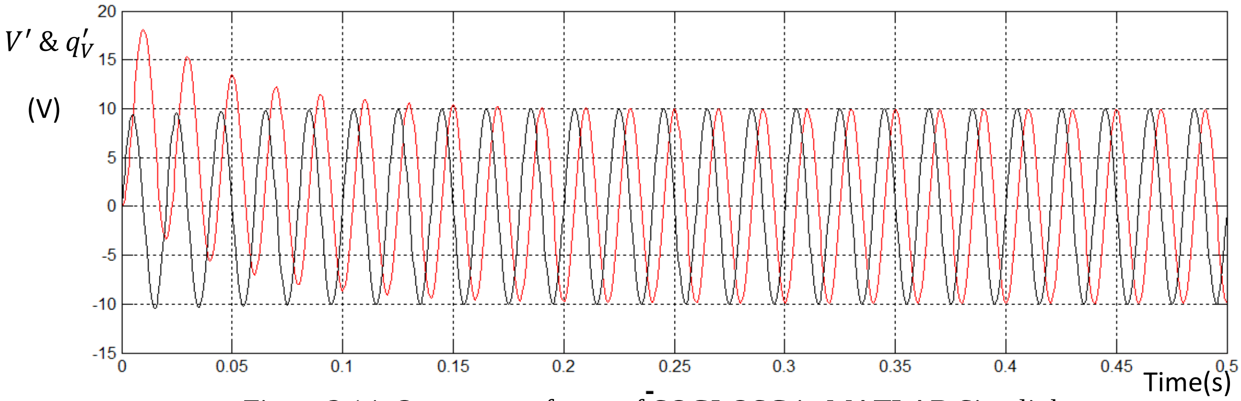


Figure 2.14. Output waveforms of SOGI-OSG in MATLAB Simulink

CHAPTER -3

Types of PLL for 3 Phase System

3.1. PARK'S AND CLARKE'S TRANSFORM

The conversion of 2 orthogonal signals in to 2 constant voltages known as Park's transform and the Clarke's transform is used to generate the 2 orthogonal signals from the 3 phase supply as shown in Figure.3.1.and Figure3.2. In geometric terms we can understand the PARK’s transform i.e., dq transformation as the projection of the three separate sinusoidal phase quantities on to 2 axes rotating with the equal angular velocity as the sinusoidal phase quantities , then control variables will act as dc values; so the filtering and controlling operation become very easier.

The Clarke’s transform is known as the projection on to the alpha beta axes i.e., stationary reference axes from the 3 phase quantities, it may 3 phase voltage or currents. The PI controller is going to fail whenever the control variables are having the nature of sinusoidal quantities i.e.,it is facing the problem with eliminating the steady state error, so for better performance it is necessary to develop other controller.

It simplifies the analysis of 3 phase circuits. It reduces the 3 AC quantities into 2 DC quantities, Calculations performed on DC quantities is easy as compared with unbalanced 3 phase supply. In two phase system there is no zero sequence components so the unbalanced voltage vector is dividing in to positive and negative sequence components.

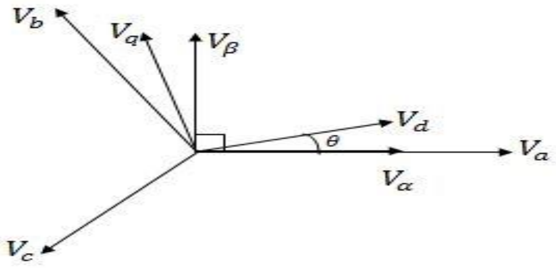


Figure.3.1. Vector representation of Clarke's and Park's transform

Because of these CLARK's and PARK's transform the analysis of power system and control is become very easy. In the above Figure.3.1. θ is the angle of shifting of the synchronous reference frame to stationary reference frame i.e., when we shift the alpha beta axes to above angle we will get the dq components . And this angle is also known as unit vector and this is the main component for the transformation and is taken as the feedback component.

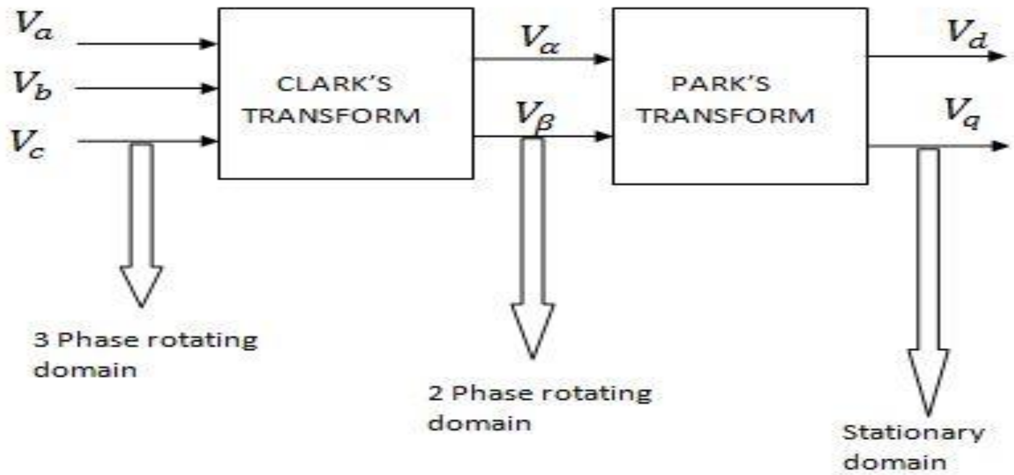


Figure 3.2.block diagram representation of Clarke's and Park's transform

$$V_\alpha = V_d \cos\theta - V_q \sin\theta \tag{3.1}$$

$$V_\beta = V_d \sin\theta + V_q \cos\theta \tag{3.2}$$

$$V_d = V_\alpha \cos\theta + V_\beta \sin\theta \tag{3.3}$$

$$V_q = -V_\alpha \sin\theta + V_\beta \cos\theta \tag{3.4}$$

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_C \end{bmatrix} \quad (3.5)$$

3.2 SEQUENCE COMPONENTS

The set of unbalanced voltages are expressed in terms of 3 sets of balanced voltages as shown in Figure.3.3. The positive sequence component can be explained as the phase sequence same as the phase sequence of the supply and consisting of 3 components of equal magnitude and displaced by 120˚ and 240 ˚. The negative sequence component can be defined as the having phase sequence opposite to the input supply and having the 3 components with equal magnitude and displaced by 240˚ and 120˚.The zero sequence components can be defined as the having the no phase sequence and having the 3 components of the equal magnitude and phase displacement of zero.

In symmetrical circuit's currents and voltages of different sequences do not react upon each other. The calculations performed on the 3 unbalanced vectors are more complicated when compared to the 3 sets of balanced sequence components of voltage. Where a is the shift operator of having unity magnitude and 120 degrees phase angle when we multiplied any signal with it ,the signal magnitude won't change but it will shifted to 120˚ in the clock wise direction.

$$E_a = E_{a0} + E_{a1} + E_{a2} \qquad (a=1\llcorner 120^\circ) \quad (3.6)$$

$$E_b = E_{a0} + a^2 E_{a1} + a\, E_{a2} \quad (3.7)$$

$$E_c = E_{a0} + a\, E_{a1} + a^2 E_{a2} \quad (3.8)$$

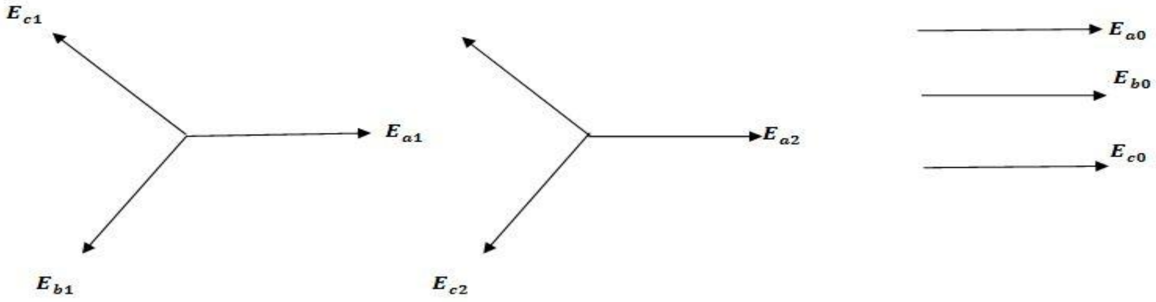


Figure 3.3. Sequence component representation for 3 phase system

3.3 SRF PLL

For finding the phase angle for the single phase system and 3 phase system The synchronous reference frame PLL can be used .for single phase system the orthogonal signal can be generated by using OSG in place of alpha beta components and in three phase it is converting the 3 phase system in to the 2 dc quantities and by using the proportional integrator (PI) the error in the angular frequency value can be found and it can be added to the angular frequency and it works efficiently in the place of loop filter. The SRF PLL block diagram is as shown in the Figure.3.4.

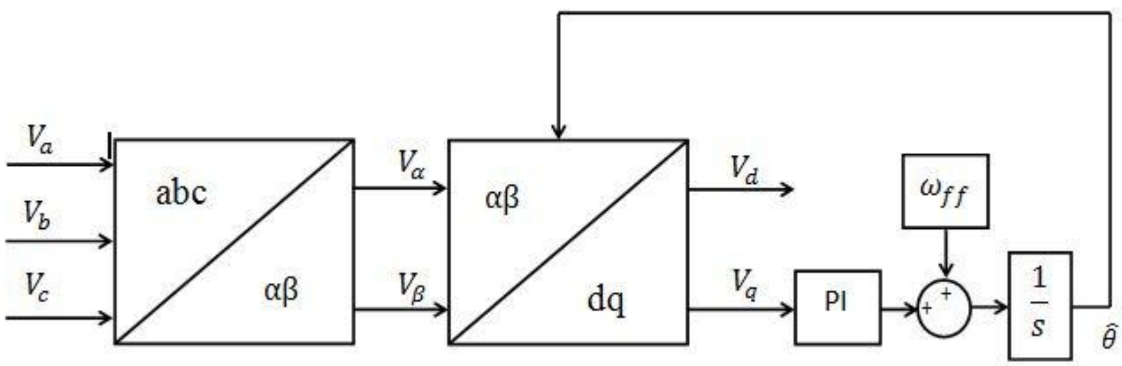


Figure 3.4. Circuit diagram of SRF PLL

Here ω_{ff} is the feed forward frequency in radians and $\hat{\theta}$ is the detected phase angle of the 3 phase input supply. Here the frequency is found by using dc component i.e. q component so that the operation by using dc quantity the chance of getting error is very less but whenever the supply is unbalanced the q component is not zero and it is having some value and oscillating with some less magnitude so in that case the error is going to increase. The SRF PLL can work efficiently for distorted and unbalanced input signals if and only if its bandwidth got reduced but for proper operation of the system the bandwidth should large ideally infinite .

3.4 DSRF PLL

In DSRF PLL alpha beta to dq transformation is used to find the phase angle as shown in Figure.3.5. When 2 SRF PLLs mixed then DSRF PLL is formed so that additionally sequence components can be calculated and dynamic performance can be improved. How the voltage vector is decomposed in to sequence components is shown in Figure.3.3. Here first 3 phase supply voltage is converted to synchronous reference frame 2 phase components and from these alpha beta components positive and negative sequence components are calculated and the positive sequence component is used for grid synchronization and negative sequence component is used for reactive power compensation. Here the positive sequence and negative sequence phase angle has been tracked .The 2 PLLs works very efficiently and independently without disturbing the system. In equation (2.6) ω is the angular frequency of the input supply. In equation ω_c is the cutoff frequency of the low pass filter, so if the cut off frequency and system frequency is equal then second harmonic ripple content can be eliminated from the system output.

3.5 SEQUENCE COMPONENT DECOMPOSITION

How the sequence components has been splitting into positive and negative sequence in the absence of zero sequence can be understood by using equations from (3.6) to (3.8), i.e. any unbalanced signal can be expressed as a sum of balanced sequence components and equation 16 shows the 3 phase to synchronous reference frame transformation where U is the magnitude of the q component after applying to the low pass filter in order to reduce the

2^{nd} harmonic ripples in the output signals. From equation (3.8) it can be clarified that there is second harmonic ripple is present in the output of DSRF PLL and if we use low pass filter with higher cut off frequency of ω_c then these ripples can be avoided.

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \tag{3.9}$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos\hat{\theta} & \sin\hat{\theta} \\ -\sin\hat{\theta} & \cos\hat{\theta} \end{bmatrix} \begin{bmatrix} U\cos\theta \\ U\sin\theta \end{bmatrix} = \begin{bmatrix} U\cos(\theta-\hat{\theta}) \\ U\sin(\theta-\hat{\theta}) \end{bmatrix} \tag{3.10}$$

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} U_+\cos(\theta_+) + U_-\cos(\theta_-) \\ U_+\sin(\theta_+) + U_-\sin(\theta_-) \end{bmatrix} \tag{3.11}$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} U_+\cos(\theta_+-\hat{\theta}) + U_-\cos(\theta_--\hat{\theta}) \\ U_+\sin(\theta_+-\hat{\theta}) + U_-\sin(\theta_--\hat{\theta}) \end{bmatrix} \tag{3.12}$$

where $\theta_+ = (-\theta_-) = \omega t$ at steady state

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} U_+ + U_-\,cos(2\omega t) \\ -U_-\,sin(2\,\omega t) \end{bmatrix} \tag{3.13}$$

$$LPF(s) = \frac{\omega_c}{s+\omega_c} \tag{3.14}$$

$$V_{\alpha+} = V_\alpha - U_-\,cos(\theta_-) = U_+\,cos(\theta_+)\ ,\ V_{\beta+} = V_\beta - U_-\,sin(\theta_-) = U_+\,sin(\theta_+) \tag{3.15}$$

$$V_{\alpha-} = V_\alpha - U_+\,cos(\theta_+) = U_-\,cos(\theta_-)\ ,\ V_{\beta-} = V_\beta - U_+\,sin(\theta_+) = U_-\,sin(\theta_-) \tag{3.16}$$

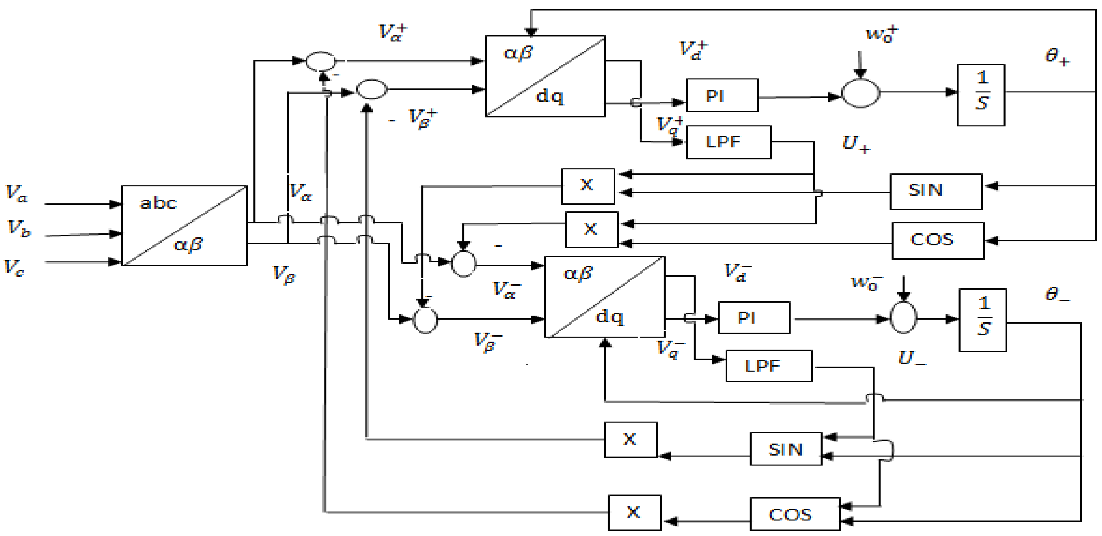


Figure.3.5. Circuit Diagram of DSRF PLL

The implementation of DSRF PLL is as shown in the fig .and here 2 SRF PLL are coming in to picture as shown .the phase angles of 2 sequence components have been tracked individually with 2 loops and positive sequence component phase angle is used for the grid operaton with the DPGS system.the sequence components output waveforms of the DSRF PLL by using the matlab simulink for 3 phase supply of magnitude 20 V is as shown in Figure.3.6.

3.6 RESULTS OF DSRF PLL USING MATLAB SIMULINK

The below results of sequence components of DSRF PLL are under the balanced supply conditions so that the negative sequence components after the 0.2 seconds becoming nearer to zero and positive sequence components are having equal magnitude of the 3 phase supply voltage. Here at 0.2 seconds it can be observed that the 2 signals i.e., alpha and beta positive sequence components and negative sequence components are orthogonal to each other. But actually the negative sequence component should become to zero for this balanced supply but there is double frequency error a little bit in the result, that is the main problem

with the PLL whichever depends on the function SRF PLL. So it is better to go for the study of the better one.

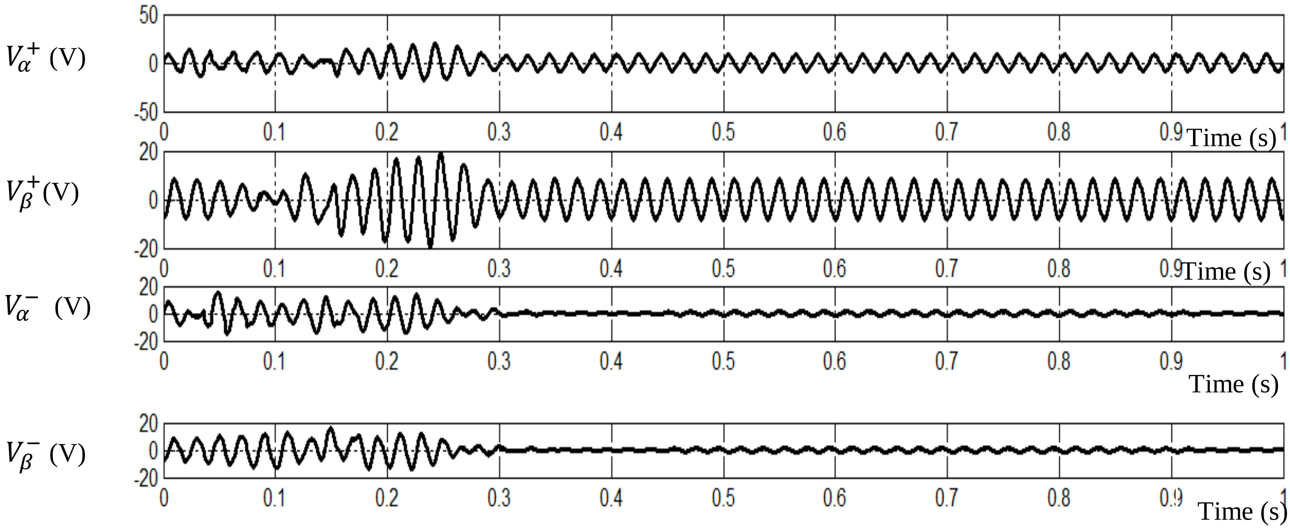


Figure 3.6 Sequence components Simulation Results of DSRF PLL

3.7 DSOGI PLL

For 2 phase system in order to calculate sequence components quadrature element and in-phase elements are needed ,here 2 SOGIs performed this duty, by using frequency locked loop we are going to extract feed forward frequency (ω_{ff}). Here in phase component and quadrature component of input signal is useful for finding the positive and negative sequence components of unbalanced input supply. By mixing the DSOGI and reference frame the in phase component and quadrature component has been generated. For the proper Interfacing of grid and inverter, the main parameters are frequency, amplitude and phase of the grid voltage.

To achieve the perfect electrical conditions like unity power factor, constant voltage etc the main is to compensate the negative sequence component and by using exact value of positive sequence component [4]. So it is necessary to finding the sequence components. And phase angle of line voltage is the factor for controlling the function of active or reactive power and to modify the feedback variables in voltage monitoring grid synchronization system.

By using Clarke's and Park's transformation the three phase utility grid voltage has been transformed from natural reference frame to rotating reference frame in SRF PLL. By using feedback loop i.e., the reference frame's angular position we can make the positive sequence component's q component to zero. Therefore the measured d-component gives the voltage vector magnitude, while its phase angle is tracked by using the feedback loop. The SRF PLL takes in a linearization assumption so the results can be guaranteed locally only. So the schemes which are based on the SRF PLL approach are sensitive to harmonic distortion. These drawbacks can be eliminated by DSOGI (doubly second order generalised integrator) PLL and additionally we can find sequence components under unbalanced condition.

3.8 SEQUENCE COMPONENT DECOMPOSISITION

The circuit diagram and output results of DSOGI PLL are as shown in Fig. How the sequence components has been splitting into positive and negative sequence in the absence of zero sequence in the case of DSOGI PLL can be understood by using equations from (24) to (30), i.e. any unbalanced signal can be expressed as a sum of balanced sequence components. Where q is the 90 degrees operator it will come in the case of orthogonal signal generation.

$$V_{\alpha\beta}^{+} = [T_{\alpha\beta}]V_{abc}^{+} = [T_{\alpha\beta}][T_{+}]V_{abc} \tag{3.17}$$

$$= [T_{\alpha\beta}][T_{+}][T_{\alpha\beta}]^{T}V_{\alpha\beta} \tag{3.18}$$

$$\text{where } [T_{+}] = \frac{1}{3}\begin{bmatrix} 1 & a & a^2 \\ a^2 & 1 & a \\ a & a^2 & 1 \end{bmatrix} \& [T_{\alpha\beta}] = \frac{2}{3}\begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{-\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{3.19}$$

$$V_{\alpha\beta}^{+} = \frac{1}{2}\begin{bmatrix} 1 & -q \\ q & 1 \end{bmatrix}[V_{\alpha\beta}] \text{ where } q = e^{-\frac{j\pi}{2}} \tag{3.20}$$

$$\text{so } V_{\beta}(j\omega) = -V_{\alpha}(j\omega) \tag{3.21}$$

$$V_{\alpha\beta}^{-} = [T_{\alpha\beta}]V_{abc}^{-} = [T_{\alpha\beta}][T_{-}]V_{abc} \tag{3.22}$$

$$= [T_{\alpha\beta}][T_{-}][T_{\alpha\beta}]^{T}V_{\alpha\beta}$$

$$\text{where } [T_{-}] = \frac{1}{3}\begin{bmatrix} 1 & a^2 & a \\ a & 1 & a^2 \\ a^2 & a & 1 \end{bmatrix} \& [T_{\alpha\beta}] = \frac{2}{3}\begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{-\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{3.23}$$

$$V_{\alpha\beta}^{-} = \frac{1}{2}\begin{bmatrix} 1 & q \\ -q & 1 \end{bmatrix}[V_{\alpha\beta}] \tag{3.24}$$

$$|V^{\pm'}| = \sqrt{(V_{\alpha}^{\pm})^2 + (V_{\beta}^{\pm})^2} \quad \text{And} \quad \theta^{\pm'} = \tan^{-1}\frac{V_{\beta}^{\pm}}{V_{\alpha}^{\pm}} \tag{3.25}$$

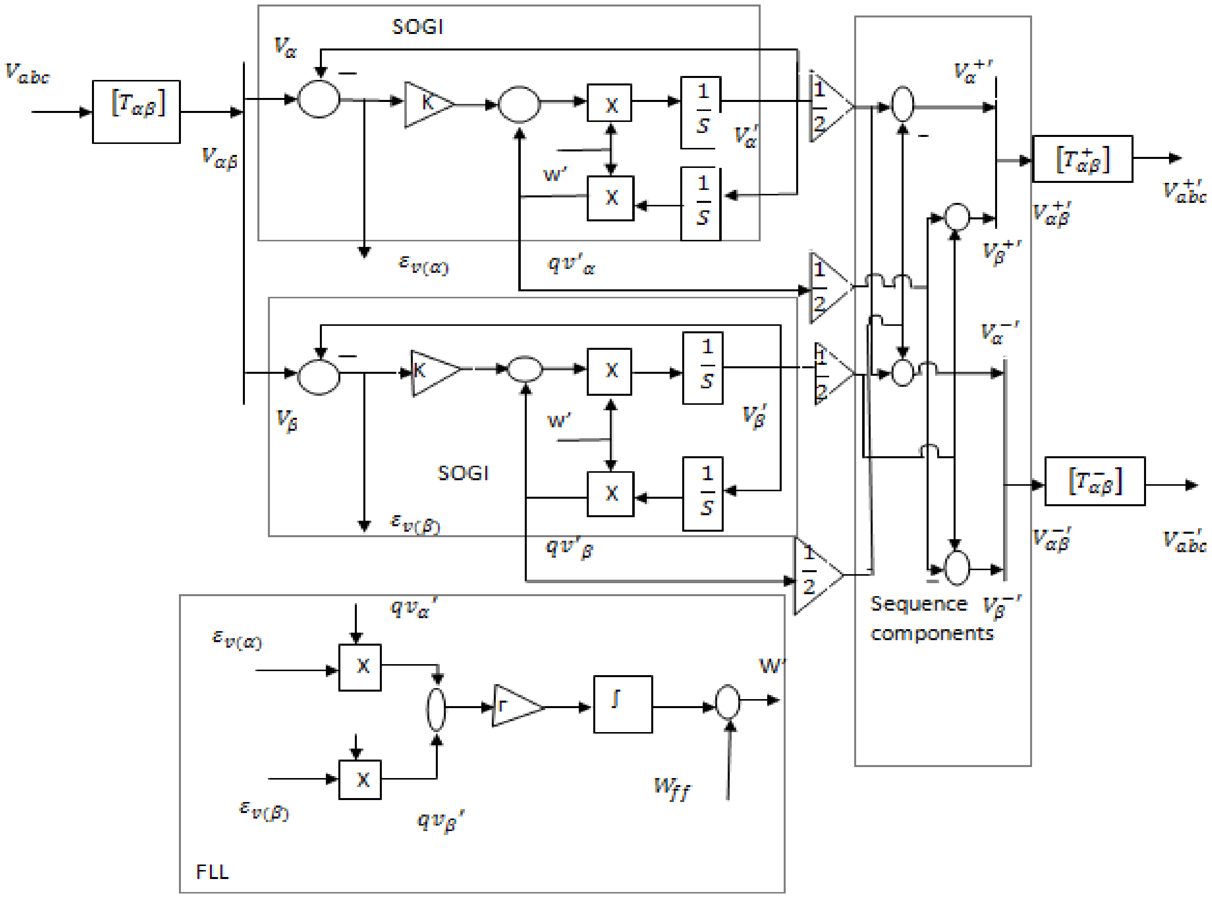


Figure 3.7. Circuit Diagram of DSOGI PLL

3.9 MATLAB SIMULINK RESULTS OF DSOGI PLL

The simulation results of DSOGI PLL using MATLAB simulink have been shown in the Figure.3.8. And Figure.3.9. The frequency output of the system is settled within 0.1 seconds. The phaseangle in radians is varied from 0 to 6.2 radians as shown. The transform of 3 phases to synchronous reference frame to stationary reference frame i.e., Park's and Clarke's transform result is shown in Figure.3.10. Here the 3 phase supply of10 V is balanced so the magnitude of resultant –ve sequence Component is zero and +Ve sequence component magnitude value is 10 V as shown in Figure.3.11. And Figure.3.12.

Here the 3 phase supply is balanced so the reactive component required is almost zero and q component of the Park's transform represent the reactive component, so its value is zero as shown. Here for 50 Hz frequency the time period is 20 milli seconds, so that there is a 5 cycles of phase angle detection in the duration of 1 second time in the phase angle result.

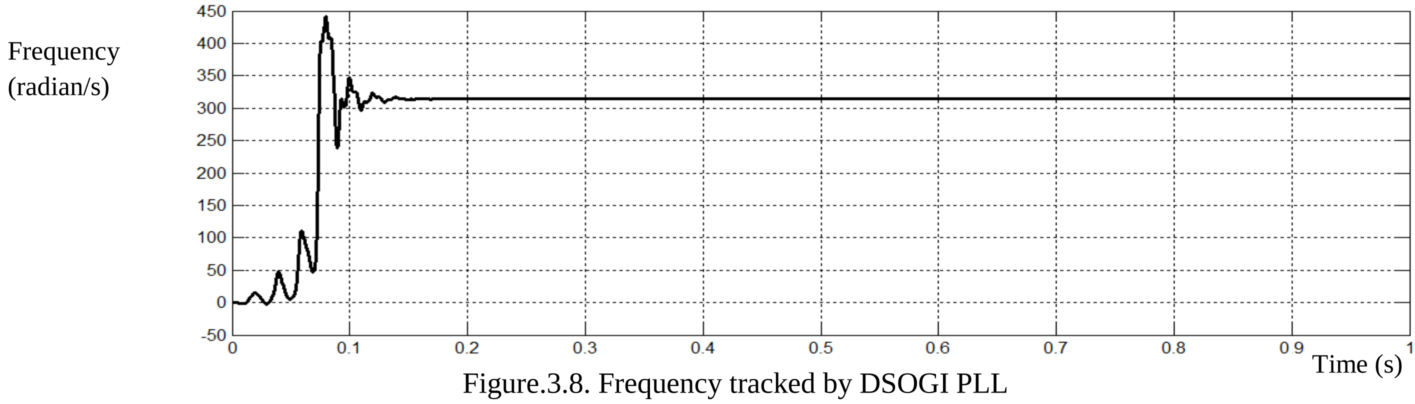


Figure.3.8. Frequency tracked by DSOGI PLL

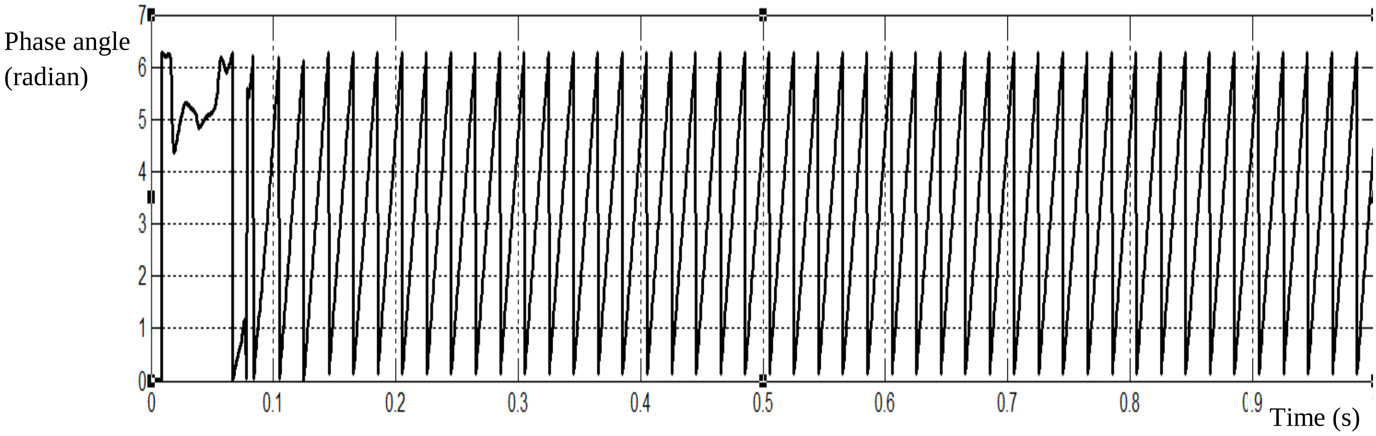


Figure.3.9. Phase angle tracked by DSOGI PLL

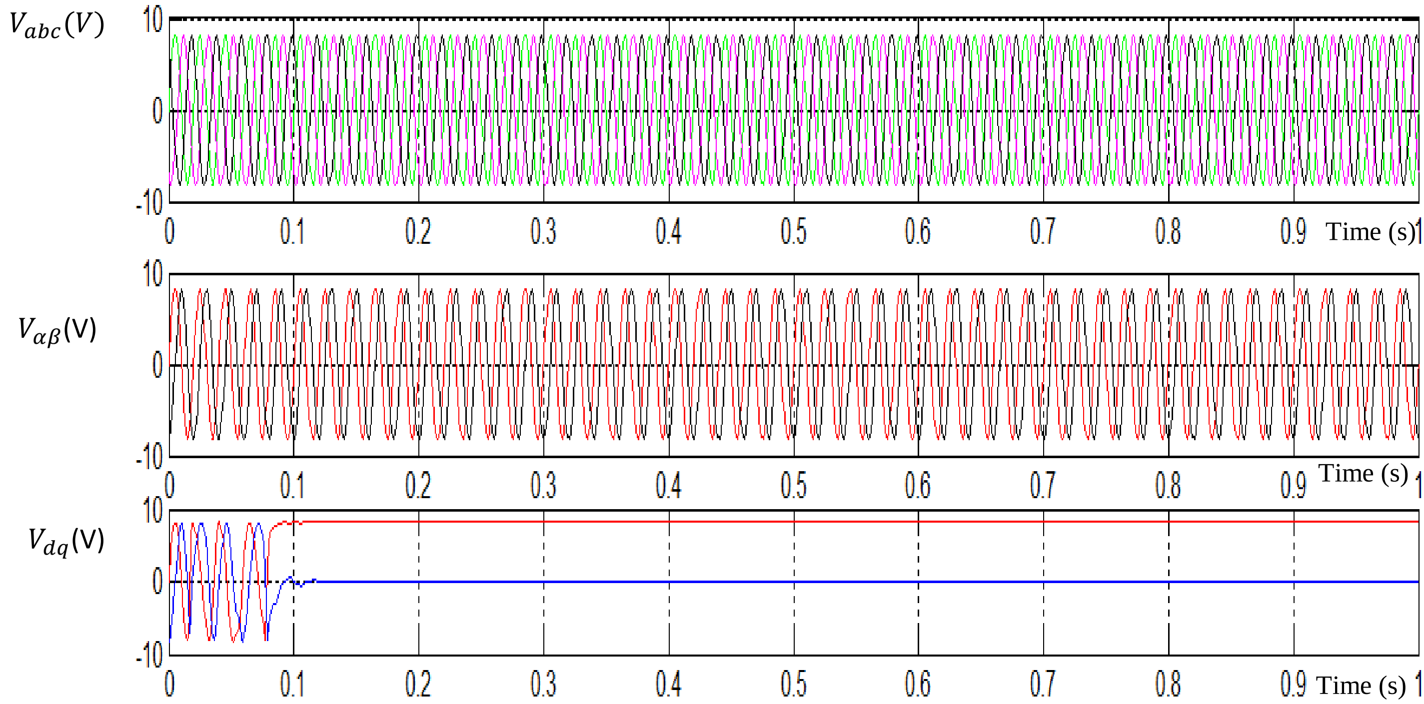


Figure.3.10. Phase to alpha beta to dq transformation

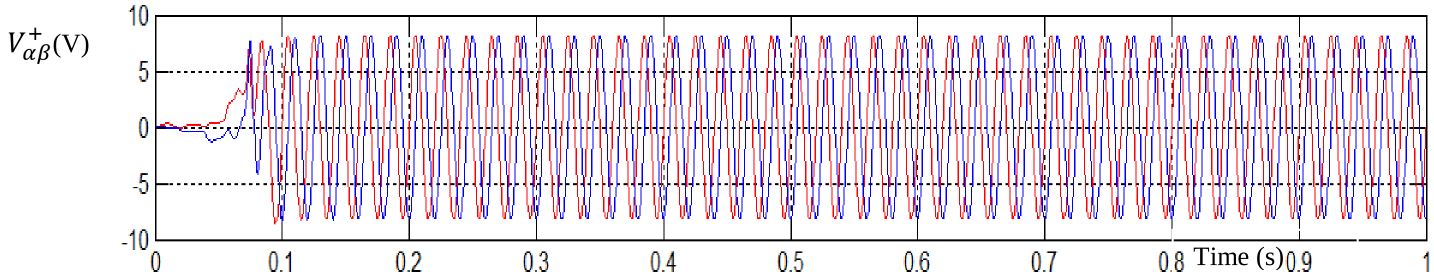


Figure.3.11. +Ve sequence component Results of DSOGI

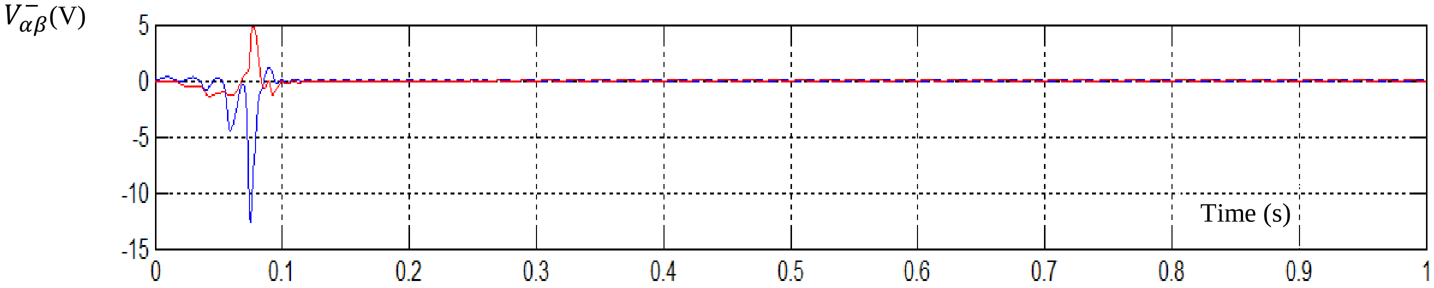


Figure.3.12. -Ve sequence component Results of DSOGI PLL

CHAPTER-4

Hardware Implementation

4.1 HARDWARE IMPLEMENTATION USING LabVIEW

In order to get the 3 phase signals from the single phase supply, the single phase supply has been shifted to 120 and 240 degrees, so if the single phase supply is considered as a phase then the shifted signals will act as b phase and c phase. By using a small and simple circuit the 120 and 240 degree phase shifters has been implemented as shown in Figure.4.1. By using 120 and 240 degree phase shifters the 3 phase signals were generated. For giving +-12 V for the Op Amp LM 741, the dc voltage has been created by using bridge rectifier circuit as shown in Figure.4.2.

Here the capacitors used are ceramic ac capacitors and it won't work for other than ceramic capacitor. The offset terminal of the op amp is kept open only that is no connection has been given means taking zero as the offset value. The resistors has been used here are having the accuracy of +-5 percent means for 10kilo ohm resistor it has the value of 10.1kilo or 9.9kilo ohm .here for getting the 6V supply single phase variac of 0 to 230 V has been used so that we can conduct the experiment at any value within the range of 0 to 10 V.

The Data Acquisition (DAQ) used here is NI USB6009 is having the specifications of maximum operating frequency is 48 kHz for all channels of total 8 channels for analog input and we can generate the digital output by using this and it has 2 ports for digital output and it has the voltage limits of +-10 V.

The hardware circuit for generating 3 phase waveform by using phase shifters has been shown. Here op amp is operated in inverting mode of operation. Here for introducing sag and swell the op amp has been used as the amplifier, for amplifier operation it should has the infinite open loop gain and infinite input impedance and zero output impedance and infinite bandwidth for ideally. The signals has been acquired by using DAQ NI USB-6009 and the signals are acquired by using continuous sampling acquisition as taking 1 sample at a time at a sampling rate of 1 kHz.

The generated 3 phase waveform is as shown in Figure.4.3.and the output of SOGI-OSG by using 5 V ac supply by using 230 to 6V transformer is as shown in Figure.4.5.The output frequency and phase angle of DSOGI PLL in LABVIEW for 5 V supply is as shown in Figure.4.4.Here the input signal frequency is not exactly 314 radians because during loading conditions the frequency the supply is oscillated around +-0.2 Hz practically i.e., at the time experiment done it is 317 radians as shown in result.

4. 2 CREATION OF SAG AND SWELL

Sag can be defined as the sudden dip in the voltage magnitude and it will happen because of short circuit or any object fallen on the transmission line system, so that there is a chance that the system will take more current from the grid and the grid may fail and the components which are connected to the grid also get damaged.

Swell is defined as the sudden increase in the voltage magnitude is because of the lightly loaded conditions. So that there is a chance of reverse flow of current from the load to the grid side and there is a chance of unnecessary tripping of the circuit breakers and there is a interruption for the power supply. Because of this sag and swell there is a chance of system get damaged. Here the sampling rate is 1 kHz so that it will show 1k samples with in 1 second.

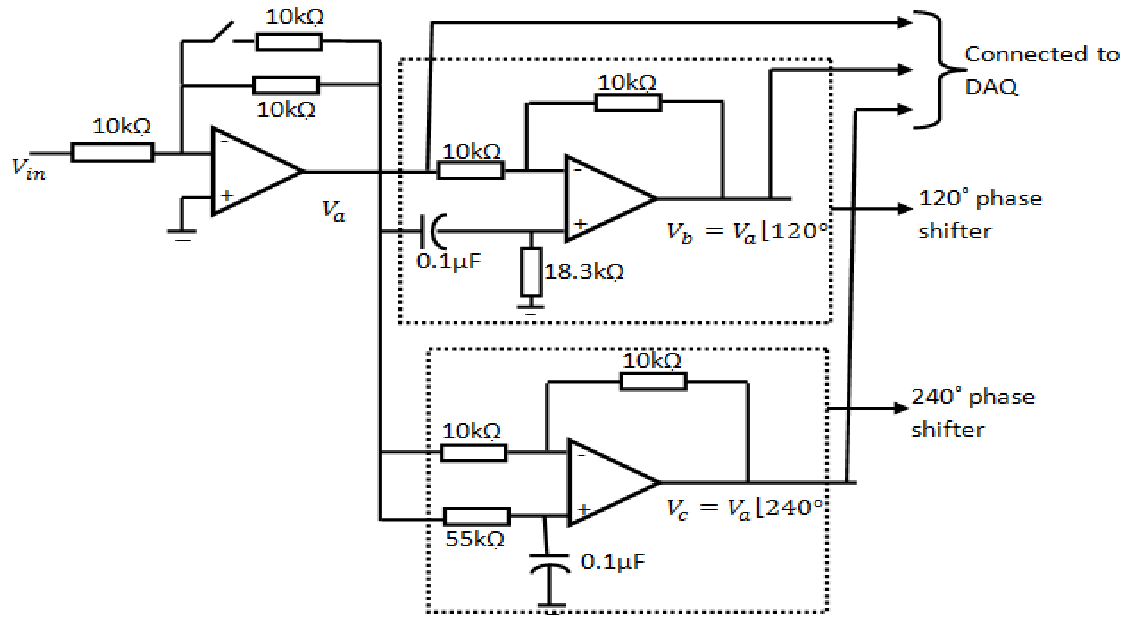


Figure.4.1. Circuit diagram of 3phase generation from single phase supply

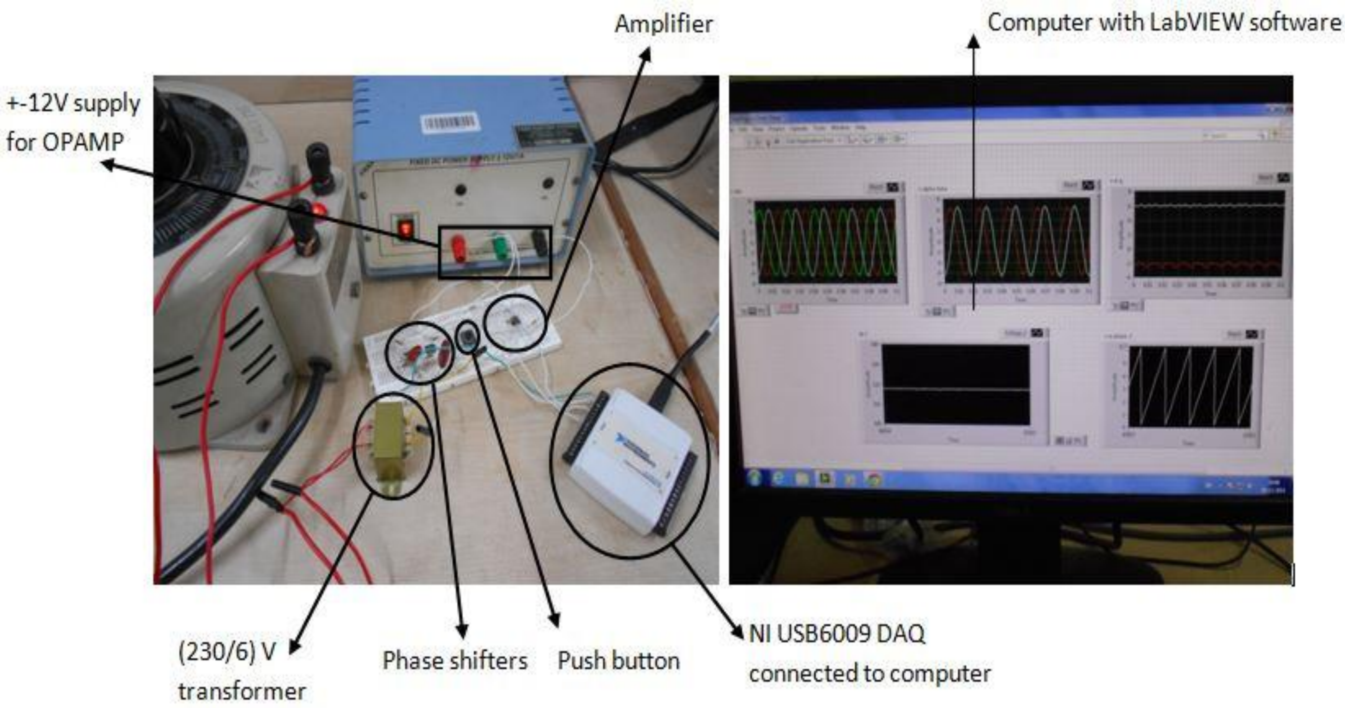


Figure.4.2. Hardware connection diagram and implementation of DSOGI PLL in LabVIEW

The push button of rating of 10V has been introduced in series with a feedback resistor of amplifier in order to create the sag and swell as shown in the Figure.4.7.

and Figure.4.11.When we press the push button suddenly then there is a decrease in the voltage for all 3 phases. Here the PLL acquiring the phase angle of fundamental component so the phase angle tracked by the PLL should be same as before the disturbance then only it is considered as working efficiently as shown in Figure.4.8.and Figure.4.12

4.3 RESULTS IN LabVIEW

The output waveforms of DSOGI PLL designed by using LabVIEW 2013 Version is shown in the below figures. Here the angular frequency of input signal tracked is 317 radians per second. The generated 3 phase signal is shown in the Figure.4.9.and Figure.4.11. and here the red color signal is the single phase supply acts as a phase and the tracked +ve sequence and negative sequence component phase angle is as shown in fig and is varied from 0 to 6.2 radians. This tracked phase has been used for Park's transform and the resultant d component and q component is as shown in Figure.4.6.

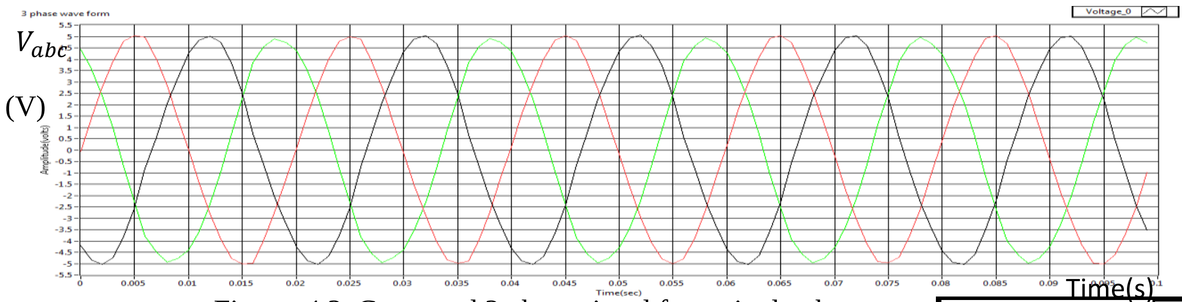


Figure .4.3. Generated 3 phase signal from single phase

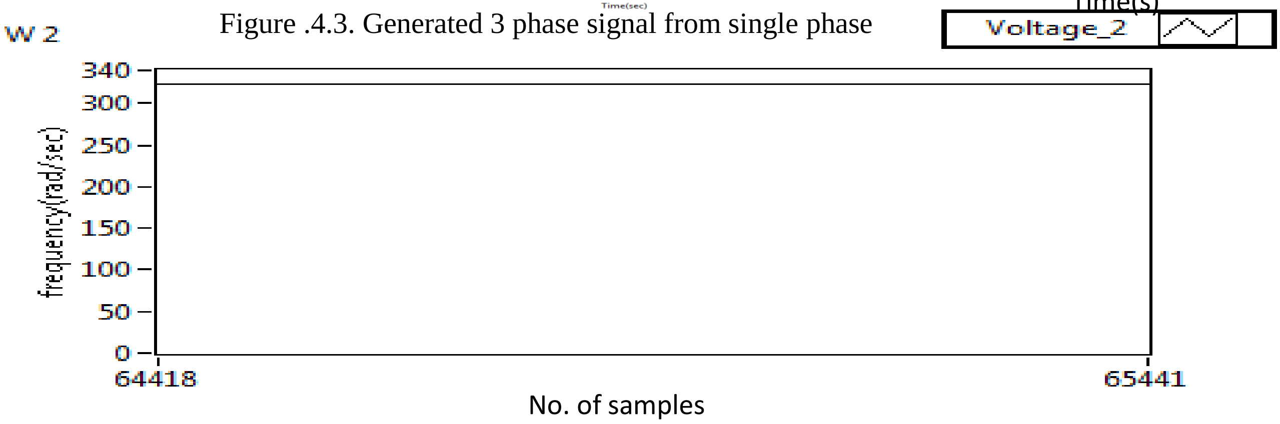


Figure.4.4. Acquired frequency by using DSOGI PLL in LabVIEW

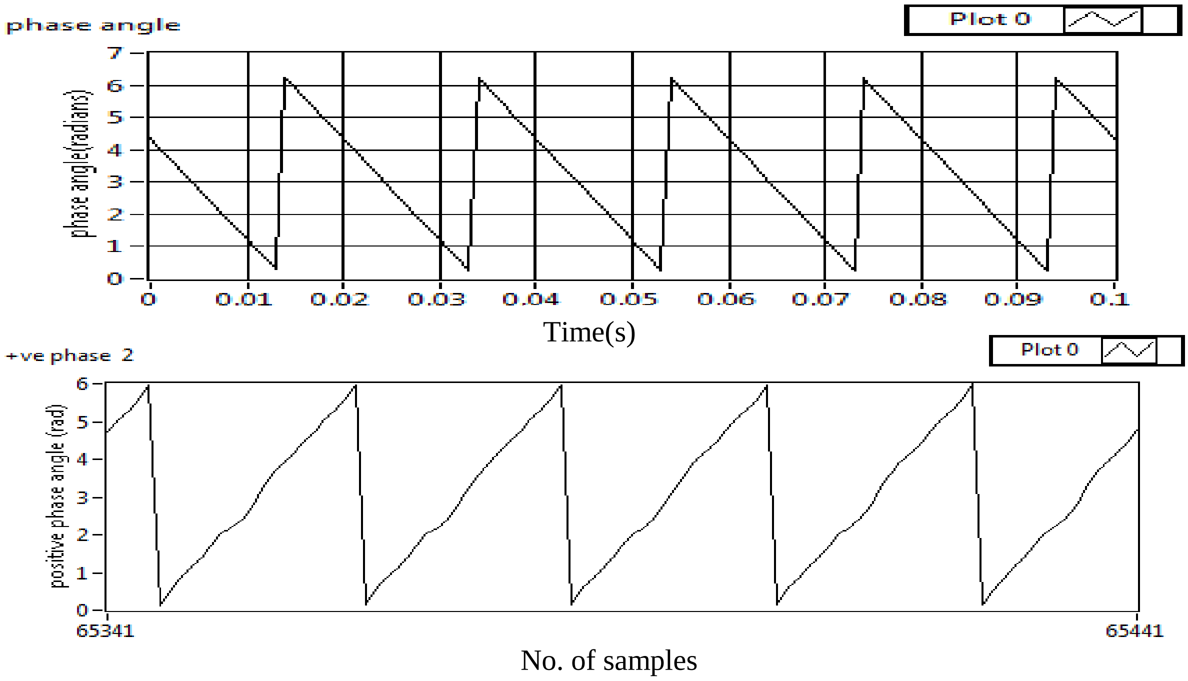


Figure.4.5. +Ve and –Ve sequence phase angle tracked by DSOGI PLL

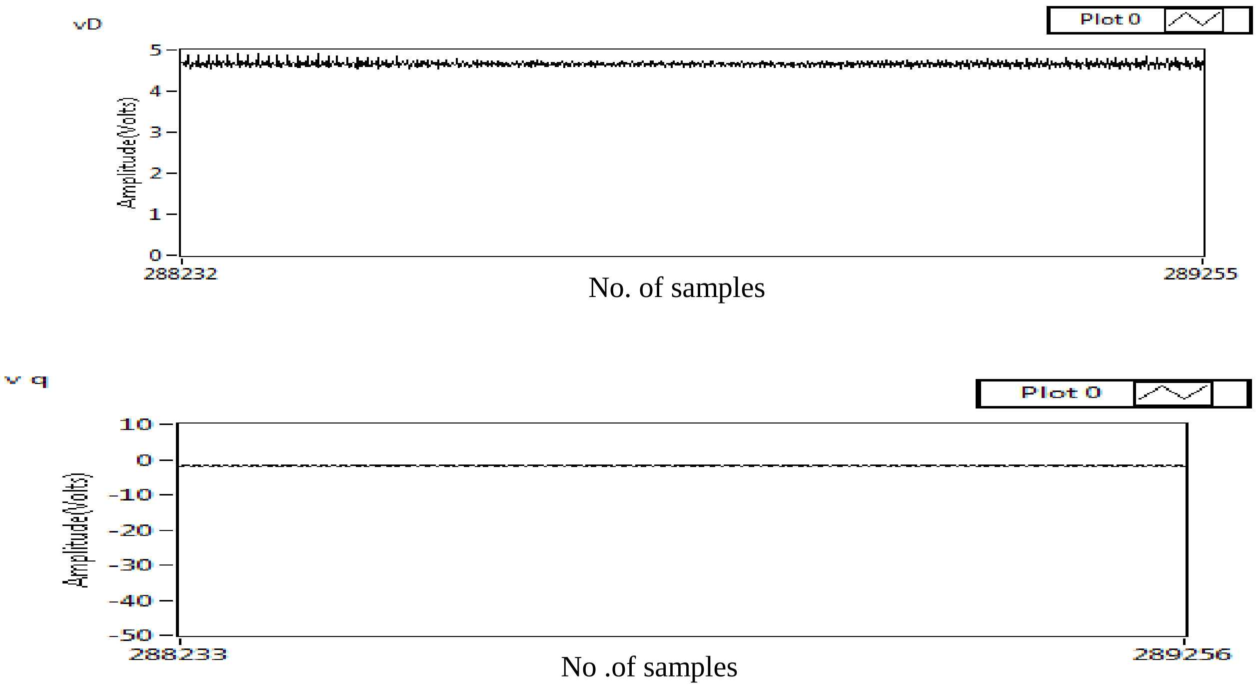


Figure.4.6. d and q component results by DSOGI PLL

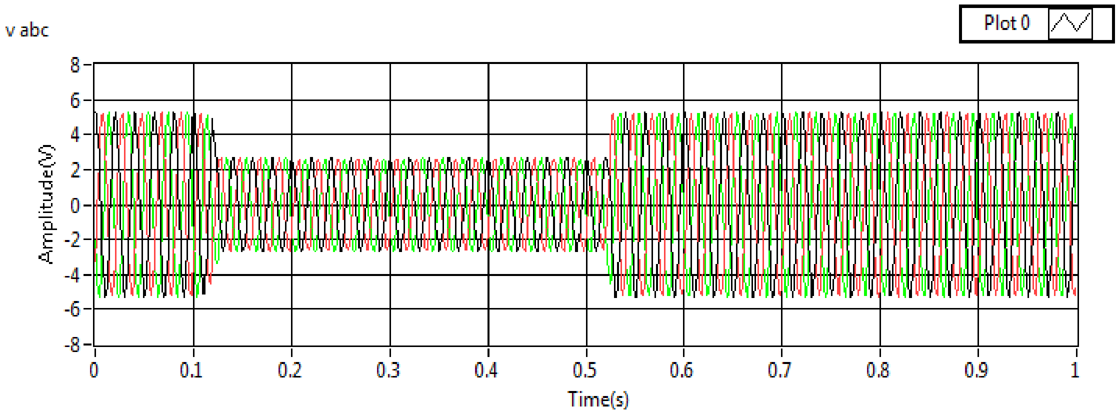


Figure 4.7. Response of DSOGI PLL for sag in all phases using Lab VIEW

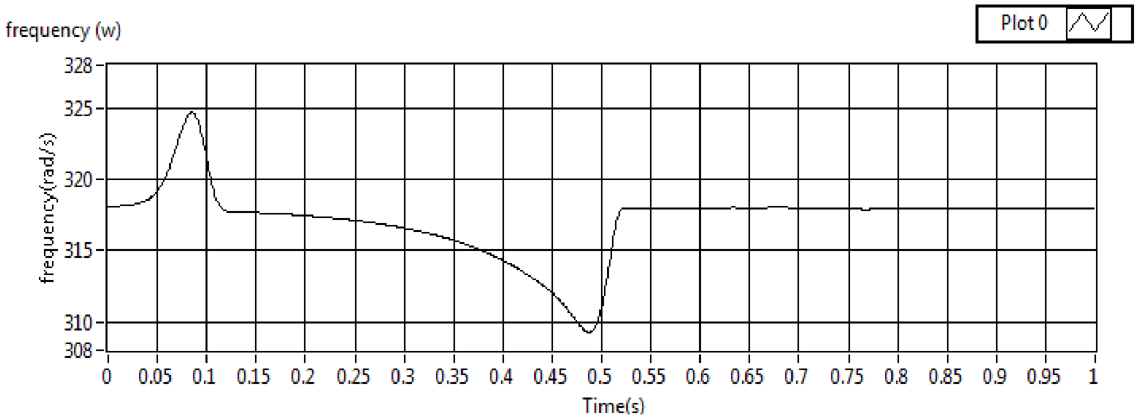


Figure.4.8. Frequency output response of DSOGI PLL for sag in all phases using LabVIEW

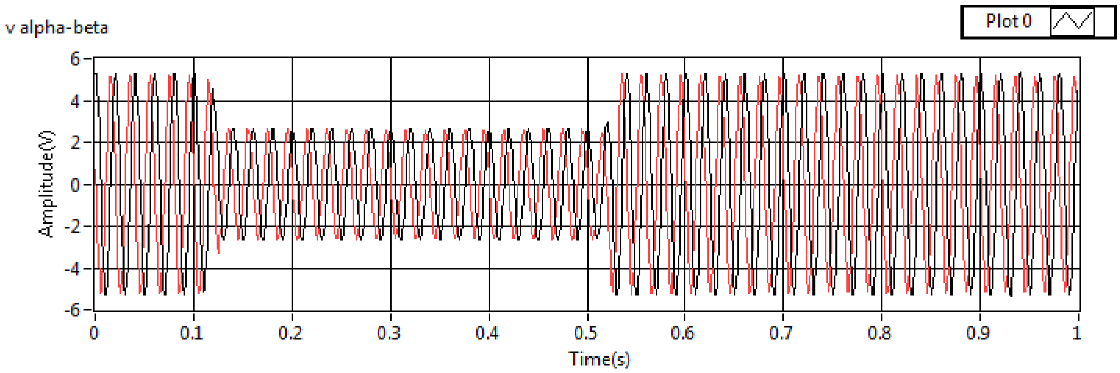


Figure.4.9. Phase angle tracked by DSOGI PLL for sag in all phases using Lab VIEW

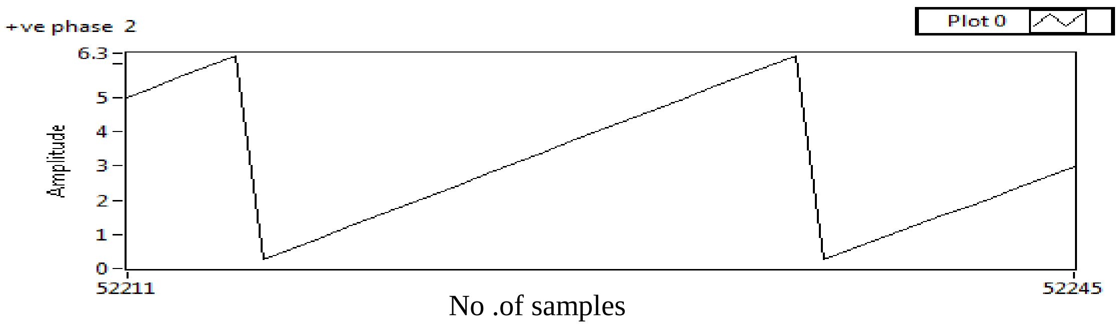


Figure.4.10. Phase angle tracked by DSOGI PLL for sag in all phases using Lab VIEW

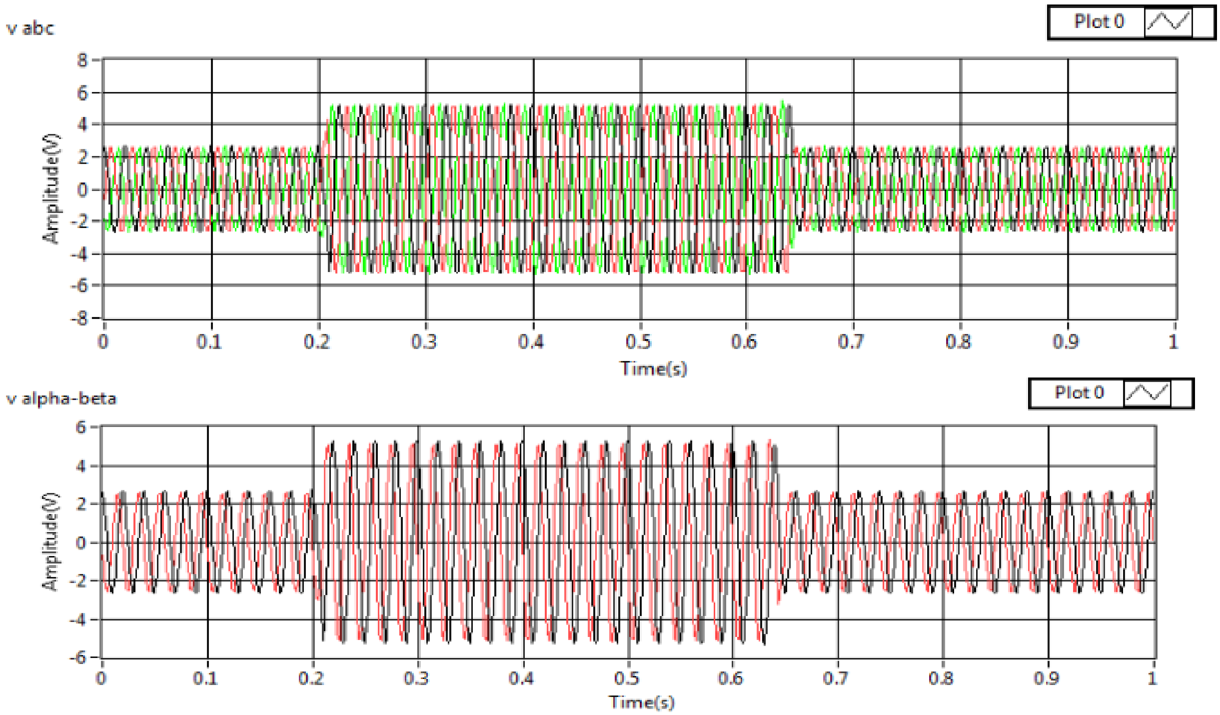


Figure.4.11. Response of DSOGI PLL for swell in all phases

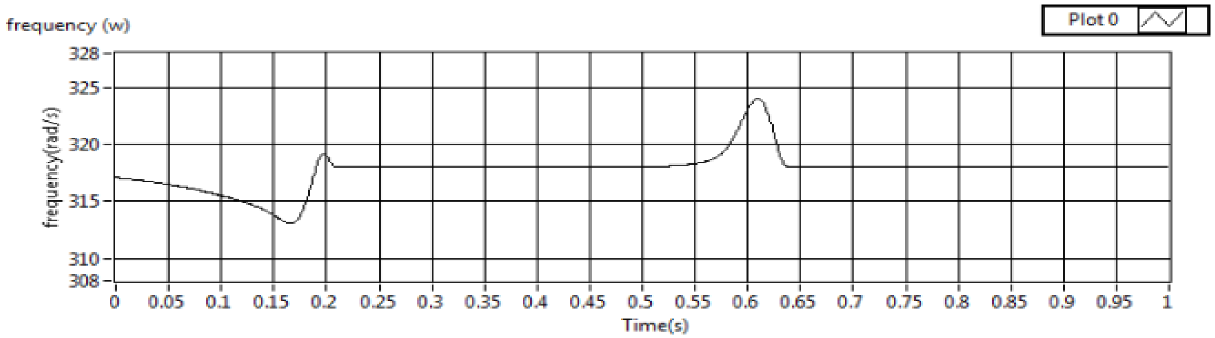


Figure.4.12. frequency response of DSOGI PLL for swell in all phases

CHAPTER-5

Conclusions and Future Scope

5.1 CONCLUSIONS

In a 2 phase system for sequence component, the quadrature signal takes an important role. OSG SOGI helps to generate quadrature signal but it can work efficiently as a frequency adaptive band pass filter, an integrator and also a small change in SOGI helps to find the frequency. Because of its selective nature of SOGI OSG it can suppress the utility voltage signal harmonic content. To control the 3 phase grid connected power converters the fundamental positive sequence component fundamental frequency or phase angle of the utility voltage under balanced and distorted condition has been tracked with the use of simple circuit. In finding the sequence components the DSRF PLL gave more oscillations as compared with the DSOGI PLL. In case of 3 phase system by using DSOGI PLL the positive sequence and negative sequence phase angle has been tracked in LABVIEW 2013 version by using DAQ NI USB6009.Here the phase angle in radians has been varied from 0 to 6.2 rad/sec. and the magnitude of d component is 6 V for input voltage of 6 V and q component has zero value in magnitude after applying Park's transform.

5.2 FUTURE SCOPE

By taking battery as DPGS and single phase supply as grid and by using DSOGI PLL and Lab VIEW software try to send back the power to single phase supply from dc battery to conform for efficient working of PLL. And if these algorithms can be implemented by using FPGA then it can be easily compared these algorithms which one is working efficiently.

REFERENCES

1. Francisco D. Freijedo, Jesus Doval-Gandoy, Oscar Lopez, Carlos Martinez-Penalver, Alejandro G. Yepes, Pablo Fernandez-Comesana, Andres Nogueiras, JanoMalvar, Nogueiras, Jorge Marcos and Alfonso Lago, “Grid Synchronization Methods for Power Converters”,Proc. of IEEE 35^{th} Annual Conference on Industrial Electronics, IECON 2009, pp. 522 - 529.
2. FANG Xiong, WANG Yue, LI Ming, WANG Ke and LEI Wanjun, "A Novel PLL for Grid Synchronization of Power Electronic Converters in Unbalanced and Variable-Frequency Environment," Proc. of IEEE International Symposium on Power Electronics for Distributed Generation Systems: pp. 466-471, 2010.
3. P. Rodriguez, A. Luna, M. Ciobotaru, R. Teodorescu, and F. Blaabjerg, "Advanced grid synchronization system for power converters under unbalanced and distorted operating conditions," in *Proc. 32nd Annu. Conf. IEEE Ind. Electron.*, Nov. 2006, pp. 5173- 5178.
4. P. Rodriguez, R. Teodorescu, I. Candela, A. V. Timbus, M. Liserre, and F. Blaabjerg, "New positive sequence voltage detector for grid synchronization of power converters under faulty grid conditions," in *Proc. IEEE Power Electron. Spec. Conf.*, Jun. 2006, pp. 1-7.
5. R. Teodorescu, F. Blaabjerg, M. Liserre, and P. C. Loh, "Proportional resonant controllers and filters for grid connected voltage source converters," *IEE Proc. Electric Power Appl.*, vol. 153, no. 5, pp. 750-762, Sep. 2006.
6. C. Lascu, L. Asiminoaei, I. Boldea, and F. Blaabjerg, "Frequency response analysis of current controllers for selective harmonic compensation in active power filters," *IEEE Trans. Ind. Electron.*, vol. 56, no. 2, pp. 337- 347, Feb. 2009.
7. MihaiCiobotaru “Grid Condition Detection and Control of Single phase Distributed Power Generation Systems”, Aalborg University. Thesis, pp.13-27 January 2009.

8. Pedro Rodriguez, Alvaro Luna, Raul Santiago and Munoz-Aguilar “A stationary reference frame grid synchronization system for Three Phase Grid connected Power converters under adverse grid conditions”. *IEEE Trans. Power Systems,* pp.99-112.2011.

9. Pedro Rodriguez, Alvaro Luna, I. Candela, R. Teodorescu "Grid Synchronization of power converters using multiple second order generalized integrators" *.IEEE Trans. Power Systems,* pp.755-760.2008.