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Study and Simulation of SOGI PLL for Single Phase Grid Connected System

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ABSTRACT

Algorithms for synchronization of grid are highly important in control of grid interfaced power converter. In order to execute stout control strategies for the interconnection of renewable energy systems with grid, rapid and precise detection of grid parameters such as amplitude, phase and frequency is critical. This paper propounds Phase Lock Loop technique for grid synchronization of single phase Distributed Generation System. Second Order Generalized Integrator (SOGI) PLL serves as Quadrature Signal Generator (QSG) which revolves around SOGI ,Parks Transform, Low pass filter (LF) and frequency phase shift generator (FPG). The QSG-SOGI and Parks Transform system is used for enhancing the performance of prevalent multiplier based phase detector (PD). Model of SOGI-PLL in MATLAB/Simulink environment is shown here.
Keywords: DGS,SOGI-PLL, Parks Transform, EPLL

I. INTRODUCTION

In recent years, the availability of energy has been an issue of great concern globally. Research is focused on increasing the generation of energy, making it cheap and economical for masses, while keeping in mind that the atmosphere should not be polluted in due course. This has increased the use of clean energy sources like solar Photovoltaic (PV), wind, biomass etc for the generation of power. PV system, provides an option to build small energy centres at residential building, offices rather than building huge generation plants. Such systems in which electrical power is generated and utilized locally are called –Distributed power generation system (DGS) [1]. The DGS can be grid connected or standalone type. Grid connected system are connected to the utility grid while the stand alone systems operate in islanded state. Grid connected systems are more efficient, cost effective and do not require any energy storage.

The grid connected DGS operates in synchronization with utility grid and pumps the active power in the grid. For accurate and rapid power transfer, grid parameters like frequency, phase and magnitude are required. Also the control strategies during the grid fault and islanding detection are based on this information[2].

Zero crossing detector (ZCD) is the basic method to detect phase and frequency. This method detects the zero crossing point of AC voltage and accordingly predicts the phase and frequency. However being simple for implementation this method is slow and updates the phase and frequency information once or twice in the input signal period [3].Also it gives poor performance in presence of harmonics.

For getting the accurate information of synchronization parameters , when the utility grid has harmonics and power quality related issues; use of Phase Lock Loop (PLL) technique has been discussed in the literature [4]-[10].In PLL , an internal oscillator is used for keeping the track of time and phase of an external periodical signal using a feedback loop.

For single phase DGS, Filho et al. [4] has explored three different PLL arrangement for grid synchronization. Rolim et al. has proposed a rugged synchronizing PLL which is based on the instantaneous imaginary and real power principle (PQ-PLL) to continue synchronism during sub-harmonics, harmonics, and unbalance in negative sequence component [5]. The other method is related to inverse park transform based PLL (park PLL). Here Synchronous reference frame PLL is adapted for single phase system where phase angle θ at a given instant is detected by carrying out synchronism between rotating frame of reference of PLL and the voltage vector of utility[4].

In this paper an attempt has been made to realize an adaptive filter based PLL for the synchronization of PV based DGS with utility grid. The adaptive filter based phase detector is implemented using a Second Order Generalized Integrator (SOGI) which has better harmonic rejection characteristics[6]. MATLAB simulation of the model is presented here.

II. METHODS AND MATERIAL

1. Phase Lock Loop

A. Basic concept

In the year 1923 Appleton proposed the fundamental concept of Phase Lock Loop (PLL) which was later given by Bellescize in 1932. Initially it was mainly used for reception of radio signals synchronously. Gradually PLL techniques were widely used in various industries in areas such as communication systems, machine control systems and power supplies working on induction heating and contactless system.

In Recent years, PLL techniques are being used for synchronization between grid-connected converters and the utility. An ideal PLL works efficiently to supply fast and accurate synchronization information with a high level of sensitivity to faults, high frequency components, unbalances, sag, swell, notches and other types of distortions in the input signal.

B. PLL Structure

The primary arrangement of a phase-locked loop (PLL) is shown in Fig. 1. It includes 3 basic blocks as shown below:

Phase detector (PD): The output signal generated by this block is equivalent to the difference of phase between the input signal v and v'. Oscillator of PLL generates the signal v'.k_{pd} is gain of Phase Detector.

Loop filter (LF): This block exhibits low-pass filtering features to eliminate the high-frequency AC parts from the Phase Detector output. Generally, this block comprises a first-order low-pass filter or a PI controller.

Voltage-controlled oscillator (VCO): AC signal whose frequency is shifted in accordance to a given central frequency, ω_c, is generated as output of this block.k_{vco} is gain of VCO.

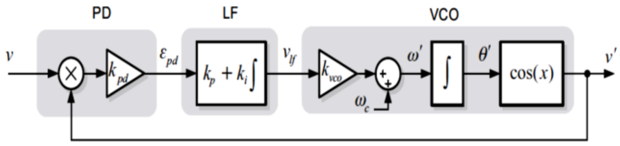

Figure1. Structure of basic PLL

C. PLL equations

Structure of an elementary PLL represents a Phase Detector which is executed with the help of a basic multiplier; PI controller is used as a LF. Sinusoidal function provided by linear integrator constitutes a VCO. The input given to PLL and the signal produced by the VCO is given by equations (1) and (2)

$$v=V sin\theta=V\sin(\omega t+\emptyset) \quad (1)$$
$$v'=cos\theta=\cos(\omega' t+\emptyset') \quad (2)$$

Multiplier PD output gives phase error signal as follows

$$e_{pd}=\frac{Vk_{pd}}{2}\left[\sin((\omega - \omega')t + (\emptyset - \emptyset')\right) + \sin((\omega + \omega') + (\emptyset + \emptyset'))] \quad (3)$$

Low pass filter cancels out higher frequency components of the Phase Detector error signal and the lower-frequency term appears in the output. Here $V_{lf}$is taken as e'_{pd}.

$$e'_{pd} = \frac{Vk_{pd}}{2}\left[\sin((\omega - \omega')t + (\emptyset - \emptyset'))\right] \quad (4)$$

When VCO is properly tuned $\omega \approx \omega'$, the DC component of the phase error signal is stated as follows

$$e'_{pd} = \frac{Vk_{pd}}{2} = [\sin(\emptyset - \emptyset')] \quad (5)$$

It is noticed in (5) that because of sinusoidal function, the phase detection given by multiplier Phase Detector is not linear in nature. When the magnitude of phase error is too small i.e. when $\emptyset \approx \emptyset'$, the multiplier Phase Detector output can be linearized in the proximity of given operating point since

$$\sin((\emptyset - \emptyset') \approx \sin(\theta - \theta') \approx (\theta - \theta').$$

Hence, when the PLL is locked, the pertinent term of the phase error signal is stated as below

$$e'pd = \frac{Vk_{pd}}{2}\,[(\theta - \theta')] \quad (6)$$

For obtaining small signal linearized model of the multiplier Phase Detector the above equation can be used.

2. Enhanced PLL(EPLL)

A. SOGI-QSG as ANF

For expulsion of particular frequency parts in the input signal, an automatic noise cancellation(ANC) technique is popular[2].To enhance the performance of the multiplier phase detector (PD) of the traditional single-phase PLL, the ANC scheme can be employed. Here ANC scheme behaves as an Adaptive Notch Filter (ANF). Grid voltage is input to ANF and a sinusoidal signal, acts as reference input signal which is contributed by the voltage controller oscillator (VCO) of the PLL. Merging an ANF and a traditional single-phase PLL results in synchronization scheme known as the enhanced PLL (EPLL).

Different solutions are mentioned in the literature for the building ANF structure [2],[4]. Second Order Generalized integrator (SOGI) based adaptive filtering arrangement is shown in the fig.2. Here *vi* is the input signal to SOGI and V_α, V_β are the output components. The transfer function of SOGI with reference to two output components can be given as

$$\frac{v_\alpha}{v_i} = \frac{k\omega s}{s^2 + k\omega s + \omega^2} \quad (7)$$

$$\frac{v_\beta}{v_i} = \frac{k\omega s}{s^2 + k\omega s + \omega^2} \quad (8)$$

Above equation suggest that the bandwidth of SOGI-based adaptive filter depends on the gain k and it is not a function of the central frequency ω. This makes it appropriate for variable-frequency operation. Using a feedback, if ω and the angular frequency of v_i are matched, (7) and (8) shows that the output components will show a phase difference of $\pi/2$. Thus a SOGI-based filtering structure can also be used for generating quadrature components. This arrangement is also called as Second Order Generalized Integrator based Quadrature Signal Generator (SOGI-QSG). The quadrature components can be represented as

$$v_{\alpha\beta} = \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = V \begin{bmatrix} \sin\theta \\ -\cos\theta \end{bmatrix} \quad (9)$$

The PD block of PLL can be developed using a SOGI-QSG. This double feedback structure provides phase angle as well as central frequency to Park transform based Phase Detector.

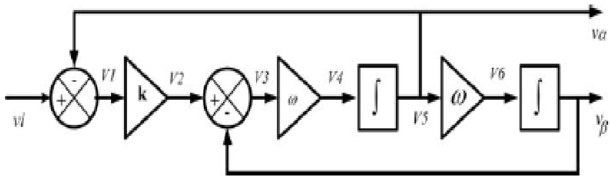

Figure 2. Basic SOGI Structure

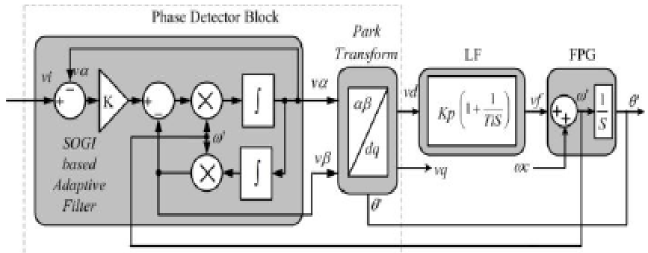

Figure 3. SOGI-QSG & Parks Transform based Phase Detector.

B. Structure of EPLL

In three phase system to convert three phase quantities into two synchronously rotating quadrature components, Clarkes Transform is used. SOGI based QSG is used in single phase system for introducing a pseudo quadrature component and the vector approach can be used. The stationary and orthogonal frame of reference is described by $\alpha\beta$ axes. It generates virtual input vector v. Signals generated as output of the Parks Transform are expressed as projections of the voltage vector v on the rotating and orthogonal frame of reference described by the dq axes as shown below

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} \cos\theta' & \sin\theta' \\ -\sin\theta' & \cos\theta' \end{bmatrix} \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} \quad (10)$$

When PD is well tuned, $\omega \approx \omega'$ and $\theta \approx \theta'$ and equation can be written as

$$v_{dq}=\begin{bmatrix} v_d \\ v_q \end{bmatrix}=V\begin{bmatrix} \sin(\theta - \theta') \\ -\cos(\theta - \theta') \end{bmatrix} \quad (11)$$

The input voltage v_α = *Vsin(θ),* can be comprehended as the image of the input voltage on the *α* axis which is stationary. PLL gives information about *θ,* which is the angular position of the dq rotating reference frame. Virtual input vector and the *dq* reference frame will have similar angular speed, when PLL will be well tuned to the input frequency (*ω ≈ ω'*). Under perfect lock conditions, 1 of the axes of the *dq* reference frame will coincide with the virtual vector input v. As per Fig.3, in steady state the PI regulator of the Low-pass Filter will settle the angular position of the *dq* reference frame such that $v_d = 0$ .It suggest that the input vector *v* will move orthogonally to the *d* axis of the rotating frame of reference. In other condition, if PI regulator is attached to the vq output of the Phase Detector as shown in fig 4, during steady state virtual input vector v will revolve coinciding the d axis of dq frame of reference. In this condition, amplitude of the input voltage vector will be given by vd signal and the phase angle identified by the PLL will have same phase as that of virtual vector v, which means that sinusoidal input voltage will lead the identified phase angle by 90 degree
i.e θ = θ' + π/2[2].

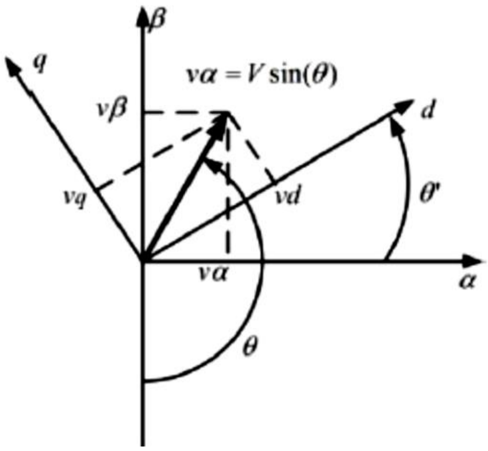

Figure 4. Vector diagram of SOGI-PARK based Phase detector

III. RESULTS AND DISCUSSION

Simulation is done using MATLAB/Simulink. Second Order Generalized Integrator (SOGI) is used to generate Quadrature signals. These quadrature signals are given as input to Parks Transform block. Parks transform is used to transform stationary frame of reference to rotating frame of reference. PI controller behaves as a low pass filter to cancel out higher frequency parts.The parameters of PI controller are very crucial as altering either of the parameters will lead the system to lose synchronism. A sinusoidal wave is given as input to the system and the performance of the PLL is checked for grid synchronization.

Simulation Parameters

Voltage Amplitude	Vi=100 volts
Voltage Frequency	314.15 rad/s
PI Controller Parameters	Kp=0.92, Ki=42.39
Cutoff Frequency	ω_c =314 rad/s

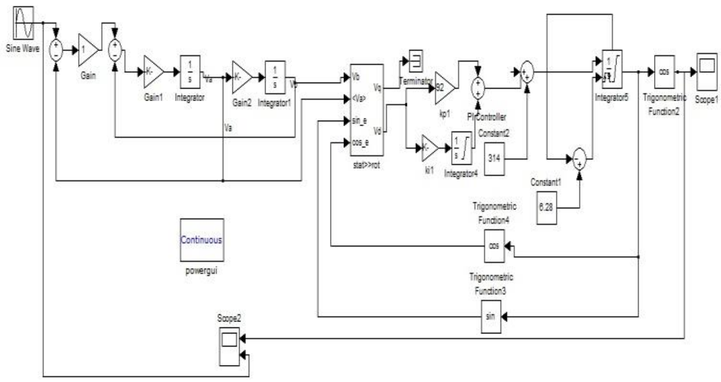

Figure 5. Simulation of SOGI PLL

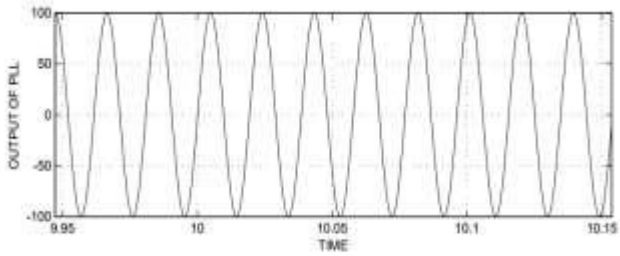

Figure 5. Output of PLL

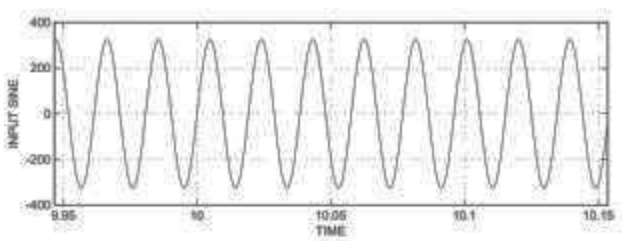

Figure 7. Input of PLL

IV. CONCLUSION

The SOGI-QSG and Parks transform based phase detector is used to replace the conventional multiplier based PD in PLL. Output signal generated by PLL matches the input signal. The input tracking is done almost instantaneously. This means that proper synchronization can be accomplished by using PLL. SOGI-QSG also improves the noise immunity of PLL and can be used under harmonics environment. Also this PLL provides the accurate information about the input signal amplitude and frequency which is essential for designing the power control strategies in grid connected Distributed Generation System.

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