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RESEARCH ARTICLE OPEN ACCESS

Inverter grid synchronization-A review and Simulation

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ABSTRACT

This paper represents the review, simulation and results of inverter grid synchronization. The converter i.e. three phase voltage source inverter is the most important part to use the renewable energy sources. The method use for inverter grid synchronization is the phase locked loop (PLL). In order to synchronize the inverter with grid in terms of voltage, frequency and phase the MATLAB SIMULINK is used. This paper also summarizes and compares different methods of synchronization in literature review section. Sinusoidal Pulse Width Modulation (SPWM) technology is also described in this paper. This method overcomes the low performance of conventional pulse width modulation technique which is use for active filter. Various simulation result are also presented to show the effectiveness of phase locked loop.

***Keywords* –** Filter, Grid synchronization, Grid tied inverter, PLL, SPWM

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I. INTRODUCTION

With rapid growth of population on the earth, the growth of energy requirement is raising so high that, it made engineers bound to think alternative to fossils and other natural resources. Our present world is demanding the use of green energy. Photovoltaic (PV) energy has great potential to provide energy with minimum impact on the environment, since it's clean and pollution free [1]. The method of using the PV or solar energy for producing electricity has already become acceptable throughout the world. Grid tie Photovoltaic inverter is now the possible solution to the energy crisis of the world. Grid tie inverters or GTI are capable of feeding large power to the grid. Another fact is photovoltaic GTI has got to be compatible with existing grid. Major function is to convert DC energy of the photo voltaic cells to AC energy, which will allow the system to connect with the grid. This attempt will take the utilization of green energy to a level must for near future. These inverters are capable of producing energy from solar energy without any environmental pollution. Various methods have been presented for controlling the grid tied inverter. This methods can be designed as current source inverter (CSI) or voltage source inverter (VSI). There are two main advantages of current source Inverter i.e. blocking reverse voltage and showing high impedance to short circuits. But still voltage source inverters are used more frequently in many applications. Because voltage source inverter has advantages such as easier control and less conduction losses. The various methods used for inverter control are sinusoidal pulse width modulation (SPWM), space vector pulse width modulation (SVPWM) and hysteresis current control (HCC). In this paper the Sinusoidal Pulse Width Modulation (SPWM) technology has been described.

II. LITERATURE REVIEW

Muhammad Ramadan, R.T. Naayagi, Woo Li Vee presents the modeling, simulation and hardware evaluation of a grid tied inverter suitable for wind energy conversion systems. The grid-tied wind generation converter converts the energy harvested from wind to DC through a static magnet synchronous generator employing a simple diode rectifier then converts it back to AC employing a pulse width modulated inverter before coupling the turbine technology to the facility grid. A closed loop simulation of the proposed set-up is modeled in PSIM environment. The hardware implementation of the proposed system is constructed using the Lab volt home energy production system and the experimental results are presented for various operating conditions. Experimental results on the grid measurements confirm that the system is able to supply the harvested energy from the wind to the grid for all wind speeds[3].

Soumya Das, Pradip Kumar Sadhu, Alok Kumar Shrivastav explains the modeling and synchronization of grid tied inverter. For a grid connected solar photovoltaic power generation system, synchronization in between generated voltage and grid voltage is the most important factor.

This paper explains the modeling and synchronization of high voltage grid connected photovoltaic (PV) power generation system. This system not only can boost up and generate DC voltage. But it also convert the solar DC power into high quality AC power by using pulse width modulation inverter to supply to the grid. For power quality improvement double tuned harmonic filter has been used. Various simulation results are presented to check the effectiveness of control method. This total system is modeled by using Sim-Power System blocks in SIMULINK library. [4].

V. Boscaino, G. Cipriani, V. Di Dio, R. Lauricella, A. Marcotulli, R. Miceli explained the various synchronization methods. Distributed power generation units are experiencing a powerful growth. Consequently, the quantity of energy injected by non-linear loads as power converters is predicted .Stability and quality of the general grid are heavily suffering from performances of grid-side converters.. Stability and quality of the overall grid are heavily affected by performances of grid-side converters. In that paper, an overview of grid-synchronization technique is proposed. The gridside inverter is implemented in MATLAB/Simulink environment including current control and grid-synchronization section. A performance comparison is carried out under ideal and unbalanced utility conditions. A modify of DDSRF architecture is proposed to enhance performances of DDSRF under distorted conditions [5].

Ines Bourguiba, Azeddine Houari, Hamed Belloumi, Ferid Kourda explained the control of single-phase current source inverter-based grid tie photovoltaic (PV) system. An intermediate DC/DC buck converter interfaces the PV source and the DC-AC inverter. A complete control structure for the Renewable energy system is presented. In source side, the algorithm is used to match the maximum power available in the PV panels. In grid side, to control the injected current into the grid, a Proportional-Resonant (PR) controller is proposed. The synchronization of the injected current with the grid is ensured by a SOGI phase-locked-loop (SOGI-PLL). Simulation results under Matlab Simulink are provided to show the effectiveness of the PR controller. In this simulations, a comparison with a classical proportional integral (PI) under clean and disturbed grid voltage conditions is performed [6].

III. OVERVIEW OF THE IMPLEMENTED RENEWABLE ENERGY SYSTEM

Fig. 1 shows the grid tied inverter scheme for renewable energy system. In this configuration, the method use for synchronization is phase locked loop. The phase locked loop gives the angle and amplitude information of grid voltages. By using this information the measured line currents and the DC link voltage which is produced by wind turbine, PV, etc. are fed to digital controller for the control of the inverter. Then, this digital controller provides the appropriate control signals to drive the switches in the voltage source inverter. At last, the filtered synchronized inverter output voltages supplied to the grid via a step-up transformer[2].

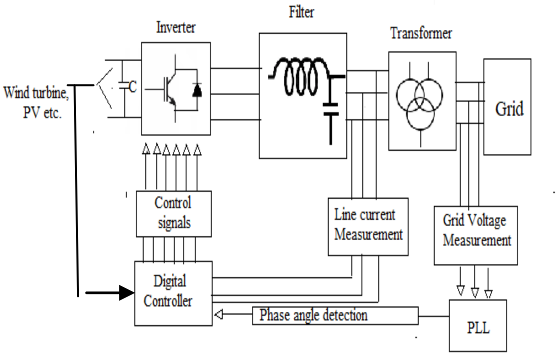

Fig.1 Grid tied inverter scheme of RES

IV. SYNCHRONOUS REFERENCE FRAME PLL (SRF PLL):

The main function of the PLL is to determine Phase angle (θ) from the angular frequency (ω) of the grid Voltage. The voltages of the three phases of the Grid (Ea, Eb, Ec) are separated in phase by an angle of 120 degree from each other. In Synchronous reference frame PLL scheme these voltages are converted into dq reference frame in a two stage transformation process i.e abc frame to αβ reference frame to dq reference frame

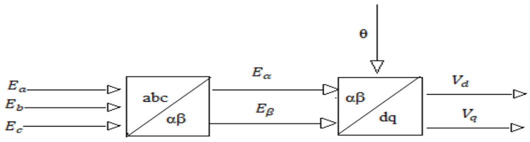

Fig.2 SRF Phase locked Loop

Fig. 2 shows the transformation block diagram. (1) describes the Three phase voltages of the grid

$$E_a = E_m \cos \omega_{grid} t$$
$$E_b = E_m \cos (\omega_{grid} t - 2\pi/3) \quad (1)$$

$E_c = E_m \cos(\varpi_{grid} t + 2\pi/3)$

Where $\varpi_{grid} t = \theta_{grid} t$

Apply the Clark Transformation i.e. (abc → αβ Transformation) to (1) we get (2)

$$\begin{bmatrix} E_\alpha \\ E_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} \qquad (2)$$

Substituting the values of E_a, E_b, E_c in (2) we get (3) as follows

$$\begin{bmatrix} E_\alpha \\ E_\beta \end{bmatrix} = E_m \begin{bmatrix} \cos\theta_{grid} \\ -\sin\theta_{grid} \end{bmatrix} \qquad (3)$$

Apply Parks Transformation i.e. (αβ → dq Transformation) (3) we get (4).

$$\begin{bmatrix} E_d \\ E_q \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} E_\alpha \\ E_\beta \end{bmatrix} \qquad (4)$$

Here the αβ denotes the stationary two dimensional reference frame and the dq denotes the two dimensional reference frame rotating with some angular velocity. Three phase voltages of the grid are rotated at an angular speed of $\omega_{grid.}$ Therefore for proper synchronization we will have to synchronize the rotation of this three phase voltages with the the rotation of the dq axis.

After simplification of Parks transformation we get (6).

$$E_d = E_m \cos(\theta_{grid} - \theta) \qquad (5)$$

$$E_q = E_m \sin(\theta_{grid} - \theta) \qquad (6)$$

For proper grid synchronization the θ must be equal to θ_{grid} .The condition for proper grid synchronization is the inverter output voltage frequency and phase equals with that of the grid voltage. Therefore if $\theta_{grid} = \theta$ then

$$E_d = E_m \text{ and } E_q = 0 \qquad (7)$$

But if there is a very small error occurs i.e if $(\theta_{grid} - \theta)$ is very small and is nearly equal to zero then

$$\text{Sin}(\theta_{grid} - \theta) = (\theta_{grid} - \theta) \qquad (8)$$

$$\text{So } E_q = E_m(\theta_{grid} - \theta) \qquad (9)$$

So we can get the angular frequency as given in (10).

$$\varpi = d\theta/dt = CEq \qquad (10)$$

Here C denotes the transfer function of the PI controller. Therefore by designing the proper controller we can successfully determine the grid utility Frequency (ϖ_{grid}) and phase (θ_{grid}).After taking the Laplace transformation of (10) we will get (11).

$$S\theta(s) = C(s)\, E_m(\theta_{grid}(s) - \theta(s)) \qquad (11)$$

Fig.3 shows the block diagram form of (11) It is the internal structure of phase locked loop. Input to PLL is grid phase angle. The PLL reduces the error and determines θ which is supplied to park's transformation block.

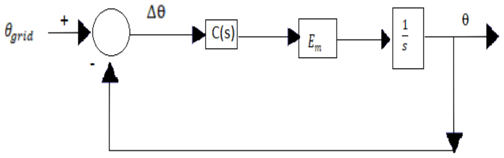

Fig. 3 Linearized model of the PLL

From (1) to (11) we can see that for grid synchronization E_q must be set to Zero. If we set $Eq = 0$ we get the overall PLL control structure as shown in the following block diagram in fig. 4. Here ϖ_0 denotes the fundamental frequency of the grid in rad/s nad E_q^* denotes the reference set point voltage of E_q[7].

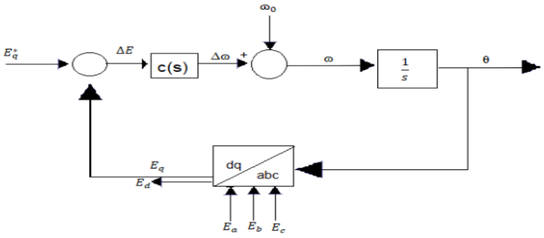

Fig. 4 Overall PLL control structure

V. CONTROL TECHNIQUE USE FOR INVERTER:

Out of all the available pulse width modulation techniques use for giving switching pulse to inverter, the Sinusoidal Pulse Width Modulation (SPWM) technique is used in this design. Generally, for the three-phase inverter three sinusoidal waves are used. These sinusoidal waves are used as reference signals. The phase difference between these reference signals are 120°. The frequency of these sinusoidal waves is selected on the basis of inverter output frequency which is required for synchronization. The triangular wave is the carrier wave having high frequency with several KHz.

When we compare the sinusoidal waves and the triangular waves switching signal for inverter is obtained. The comparator compares these two waves and when the sine voltage is greater than the triangular voltage it produces the pulse. And then this pulse is used to trigger the corresponding inverter switches. The switches of any leg in the inverter should not be switched off simultaneously because if we switch of switches of any leg of inverter simultaneously, it causes the undefined switching states and undefined AC output line voltages in the VSI. The phase outputs of the inverter are mutually phase shifted by 120° angles. The conventional sinusoidal pulse width modulation signal generation technique for the three phase voltage source inverter is shown in fig.5.

The total harmonic distortion is not affected by the PWM process because the root mean square value of the ac voltage waveform and the dc bus voltage is same. The inductances in the ac system automatically filtered the harmonic components in the system .

The modulation index is defined as the ratio of amplitude of the modulating signal A_m to the amplitude of the triangular carrier is A_c i.e. m = A_{m}/A_c . By controlling the modulation index we can control the magnitude of the applied output voltage. Due the presence of the inductive elements the high frequency components don't propagate significantly within the ac network with a sufficiently high carrier frequency. Generally switching frequencies in the range the 2-15 kHz is considered which is adequate for power systems applications.

In figure, the carrier wave signal is denoted by V_{tri}, control signal is denoted by $V_{control}$, inverter output line to neutral voltages are denoted by V_{AO}, V_{BO}, V_{CO}, inverter output line to line voltages = V_{AB}, V_{BC}, V_{CA} , the frequency of the V_{tri} = f_s, the frequency of the $V_{control}$ is f_1, f_s = PWM frequency and f_1 = fundamental frequency.

The inverter output voltages are determined by (12) & (13).

When $V_{control} > V_{tri}$,

$$V_{AO} = V_{dc/2} \quad (12)$$

When $V_{control} < V_{tri}$,

$$V_{AO} = -V_{dc/2} \quad (13)$$

where, $V_{AB} = V_{AO} - V_{BO}$

$$V_{BC} = V_{BO} - V_{CO} \quad (14)$$

$V_{CA} = V_{CO} - V_{AO}$

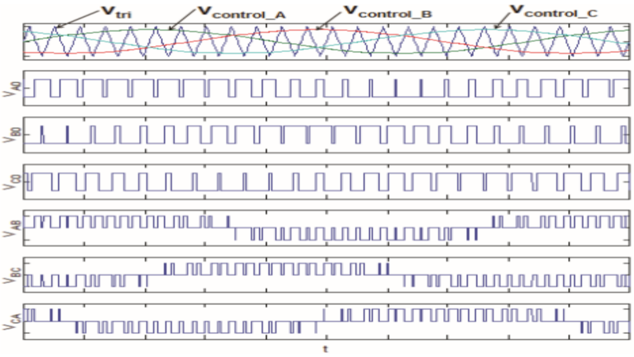

Fig. 5 Principle of Pulse Width Modulation

A. Advantages of SPWM:

- Its implementation and control is easy,
- Linearity,
- It is compatible with digital microprocessors,
- It dissipates lower power,
- It has lower switching losses,
- Better utilization of the DC power supply that is to deliver a higher output voltage with the same DC supply,
- Low harmonic contents in the output voltage and ac currents, especially in the low-frequency region.

VI. SYSTEM CONFIGURATION:

The simulation of inverter grid synchronization is completed using simulink. Fig. 6 shows the simulink model of Grid Tied Inverter. Here the PI controller is used to reduce the error. Two loads are connected after the V- I measurement block. The V-I measurement block measures the three phase voltage and current. The system parameters utilized in simulation are listed in Table1.

Table 1: Simulation Parameters

Sr. No.	Parameters	Value
1.	Three phase peak voltage	330V
2.	DC supply	650V
3.	Supply frequency f_s	50HZ
4.	Filter Inductance L_f	3mH
5.	Inductor internal resistance R_f	0.05Ω
6.	Filter capacitance	30µF
7.	Capacitor resistance	0.5Ω
8.	Load 1	R=30Ω, L=75mH
9.	Load 2	R=10.29Ω, L=25.86mH

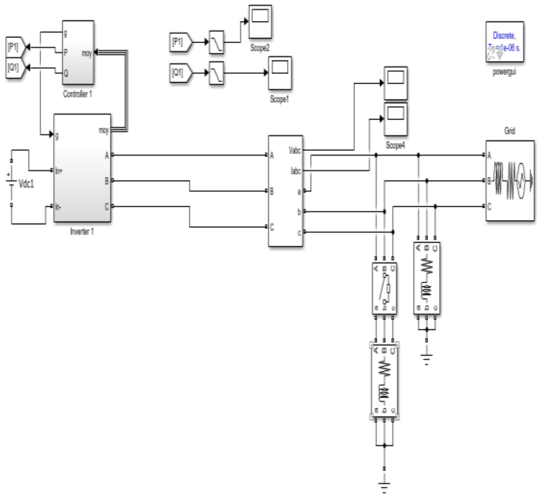

Fig. 6 MATLAB simulink model of grid tied inverter

VII. SIMULATION RESULTS:

Fig. 7 shows the inverter output current is nearly in phase with grid voltage. This happened because of the tracking ability of PLL and PI controller at the instance when the q axis current reference is set to zero. The inverter output current is synchronous with grid voltage. It can be seen that grid voltage is nearly in phase with output inverter current, it means that the control algorithm satisfies the condition of zero value of the reactive power. Fig. 8 shows the inverter output and grid voltage. From waveform it is observed that the voltage of inverter and grid are same both in magnitude and phase. This is the condition for inverter grid synchronization. Therefore by using dq PLL method proper synchronization can be achieved.

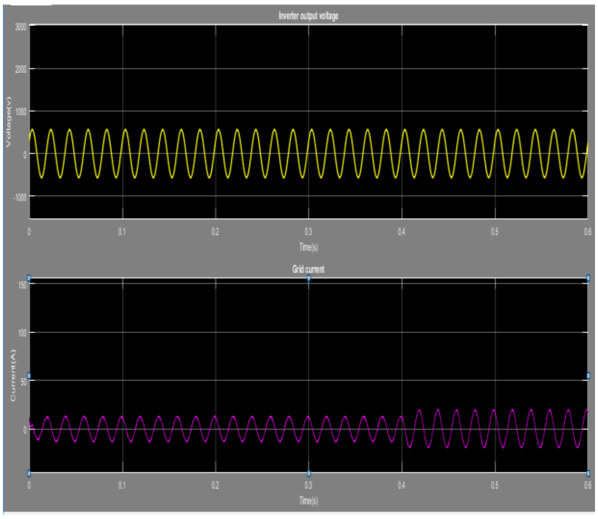

Fig.7 Inverter output voltage and grid current

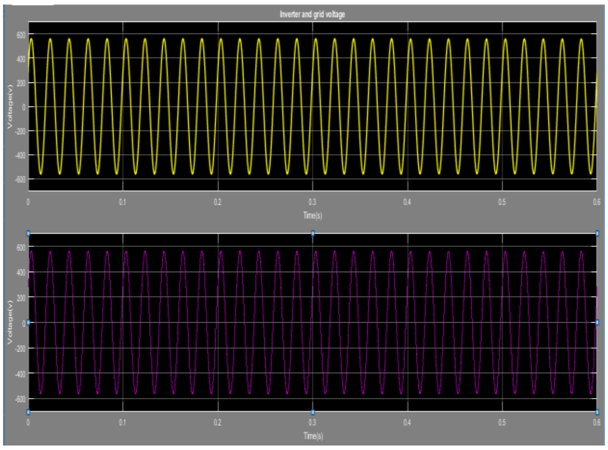

Fig. 8: Inverter output and grid voltage

VIII. CONCLUSION:

In this paper the method use for synchronization i.e. dq-PLL method, its review and SPWM technique is discussed. From this paper the inverter and grid voltage, Inverter output voltage and grid current waveforms are observed. Then we used PI controller and

SPWM technique for controlling of inverter. The advantage of PI controller is that there is no any remaining steady state error after a set point changed. The advantages of SPWM are Its implementation and control is easy, It dissipates lower power, It has lower switching losses etc. The dq PLL method is used to determine grid phase angle and voltage. All simulation results shows that the of the SPWM controlled grid tied inverter output voltage are balanced with the grid voltage and grid synchronization is successfully achieved by using dq-PLL. 9. Acknowledgments: This work

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