DESIGN OF PV-WIND THREE PHASE GRID CONNECTED SYSTEM USING PLL

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Abstract—*Energy is the primary source for all the work done by the human. Rapid growth in domestic and commercial application has increased the demand of energy in developing countries. Since the source of sectors in getting the non-renewable energy such as fossil fuel is reduced, it is necessary to look at for the alternate source to satisfy the demand of human beings. The only alternate source for the engineers is renewable energy such as solar, wind, biomass, ocean and geothermal. In this paper, hybrid energy source (wind and solar) is employed for the power generation using phase locked loop (PLL) for the frequency phase matching. The individual renewable energy sources are not available at any time and the hybrid energy source may satisfy the demand. The continuous generated energy can be transported to farther distance, pollution free and cost effective when compared with geothermal and ocean. The main aim of this paper is to reduce the number of converters and to supply the energy to the end-users continuously using phase locked loop (PLL).*

Keywords— Wind, Solar, PI Controller, Converter, Phase locked-loop, Grid

1. INTRODUCTION

Increased industrialization and household energy utilization has resulted in the demand of energy mainly electricity. The lack of non-renewable energy resources increase the fuel cost and dangerous emission from the burning of fossil fuels from power generation is unsustainable. Energy is a fundamental constitute of economic development and also essential for increasing population. Hybrid electricity generation system is far more reliable than a single source of energy. Isolated power systems using renewable energy sources like sun, wind, hydro, biomass etc. can be used to supply electricity for unreachable locality and they can be cost-effective in the long run. Phase-Locked Loop is a closed loop frequency control system, which function is based on the phase sensitive detection of phase difference between the input and output signals of the controlled oscillator (CO). The Phase Locked Loop method of frequency synthesis is now the most commonly used method of producing high frequency oscillations in modern communications equipment. The frequency and the phase angle of the input system should match with that of the grid requirements. The synchronization process is done by PLL. It matches the frequency of the input system with that of the grid. Thus, it reduces the error and improves the efficiency. The use of Phase Locked Loops (PLLs) for grid synchronization provides better response. In this paper, modelling of wind and solar power sources and synchronization with grid is proposed. The PV system and the wind system are modelled. It is then combined to form a hybrid system. This hybrid system is synchronized with the grid using PLL. The stand-alone system is designed and it is connected with the hybrid system for synchronization with the grid. The voltage magnitude and frequency of the system is analysed.

2. HYBRID ENERGY SYSTEM

The term Hybrid refers that the combination of two or more systems. In Renewable Energy Systems (RES), the Hybrid energy system refers to the combination of two or more RES devices. This system overcomes the disadvantages of the stand-alone RE conversion systems.

Hybrid Energy systems can address limitations such as,

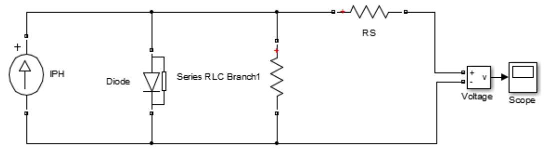
- Flexibility
- Efficiency
- Reliability
- Emissions
- Economics

A. Need for Hybrid Energy System

The disadvantage of stand-alone renewable system is their power generation is intermittent and depends on weather Conditions. In the hybrid system, power will be produced even when there is no source for any one RES device. For example, in a Solar-wind hybrid system, power production must be ensured even when there is no source for any one of the generation system. In night time, solar input will be zero hence the wind can generate the rated supply from the system. In day time, the power can be produced with the help of both the sources. For many applications, the combination of renewable energy sources compares favourably with the fossil fuel based systems, both in regard to their cost and technical performances. Because these systems employees two or more different sources of energy, they enjoy a very high degree of reliability as compared to single source systems such as a standalone solar PV system or a standalone Fuel-Cell system. Application of hybrid energy systems range from small power supplies for remote households, providing electricity for lighting and other essential electrical appliances, to village electrification for remote communities has been reported. The concept of having hybrid power stations is not new, but has gained popularity in recent years. Hybrid energy stations have proven to be advantageous for decreasing the depletion rate of fossil fuels, as well as supplying energy to remote rural areas, without harming the environment.

B.Photo Voltaic Cell

The general model is composed of photo current source, diode and parallel resistor expressing the leakage current, and series resistor describing the internal resistance to the current flow.



The I-V characteristic equation of a PV cell is given as:

$$I = I_{ph} - I_s\left(exp\left[q\frac{[V+IR_s]}{KTA}\right] - 1\right) - \frac{(V+IR_s)}{R^{SH}} \text{ ----- (1)}$$

where I is a light-generated current or photocurrent is the cell saturation of dark current, q (= 1.6 × 10-19 C) is the electron charge, k (= 1.38 × 10-23 J/K) is Boltzmann constant, T is the cell working temperature, A is the ideal factor, RSH is the shunt resistance, and RS is the series resistance. The photocurrent mainly depends on the solar insulations and cell working temperature, which is given as:

$$I_{PH} = \lambda(I_{SC}+K_I(T-T_r)) \text{ ---------- (2)}$$

Where ISC is the cell short-circuit current at a 25 °C and 1 kW/m2, KI is the cell short-circuit current temperature coefficient, T_r is the cell reference temperature, and λ is the solar insolation in kW/m2. On the other hand, the cell saturation current varies with the cell temperature, which is described as:

$$I_S = I_{RS}\left(\frac{T}{T_r}\right)^3 exp\left[qE_G\frac{\left(\frac{1}{T_r}-\frac{1}{T}\right)}{KA}\right] \text{ --------- (3)}$$

Where I_{RS} the cell reverse saturation is current at a reference temperature and a solar radiation EG is the band gap energy of the semiconductor used in the cell. The ideal factor A is dependent on PV technology.

The reverse saturation current at reference temperature can be approximately obtained as:

$$I_{RS} = \frac{I_{SC}}{EXP\left(\frac{qV_{OC}}{N_S KAT}\right)-1} \text{ ---------- (4)}$$

Since a PV cell produces very low power, the cells should be arranged in series-parallel configuration on a module to produce enough power. As mentioned earlier, PV array is a group of PV modules which are connected in series and parallel circuit configurations to generate the required current and voltage. For an ideal PV cell (no series loss and no leakage to ground, i.e., RS = 0 and RSH = ∞, respectively). The equivalent circuit of PV cell can be further simplified.

$$I = N_P I_{PH} - N_P I_s\left[exp\left(\frac{qV}{N_S KTA}\right) - 1\right] \text{ -------- (5)}$$

C. Wind Energy System

The wind energy system consists of wind turbine and generator. The generator can be either induction or synchronous. The most commonly used generator in the wind energy conversion system nowadays is permanent magnet synchronous generator. The PMSG can produce efficient power when compared to other machines. The three inputs are the generator speed in Pu of the nominal speed of the generator, the pitch angle in degrees and the wind speed in m/s. The tip speed ratio λ in Pu of λ nom is obtained by the division of the rational speed in Pu of the base rotational speed and the wind speed in Pu of the base wind speed.

3. PROPOSED METHODOLOGY

Power generation is done by hybrid energy. The DC power from photovoltaic panel is converted into AC using three phase voltage source inverter and is sent to AC line along with wind power. The generated power is distributed to load through grid. Proposed method is designed with three phase voltage source inverter, PI controller with and without PLL is shown in the figure 1 and figure. The results are analysed.

A. ***GRID CONNECTED INVERTER WITH AND WITHOUT PI CONTROLLER***

The voltage and current control is done using without PI in the grid side as shown in fig. 1 a. Voltage control controls the power flow by controlling the phase angle between the inverter output voltage and grid voltage. Current control controls the power flow by controlling the active and reactive components of current injected into the grid and is less sensitive to the distortion in grid voltage and also is it faster in response.

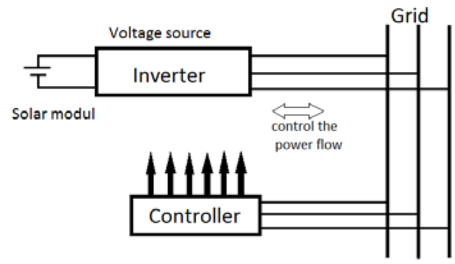


Fig.1 a: Basic Block Diagram of Gird Connected Inverter

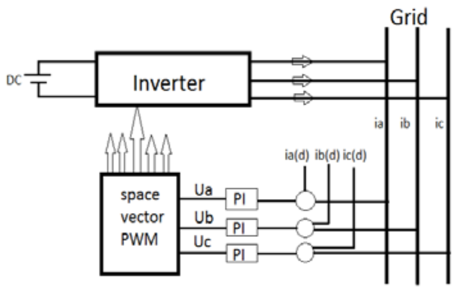


Fig.1 b: Basic Block Diagram of Gird Connected Inverter with PI controller

In current control method, if the grid current is measured in stationary reference frame then PI current controller as shown in fig. 1 b, will fail to remove the steady state error. The current is sinusoidal, it will continuously change with respect to time. The sinusoidal grid current is transformed into the rotating reference frame that rotates synchronously with grid voltage (using park transform). Hence PI controller is varied to convert ac to dc. The uncontrolled current is controlled to the grid which is in phase with the grid voltage. So the phase angle θ used in a b c/dq, Clarke transformation model has to be extracted from grid voltage. This can be done by PLL technique and it became a state of the art in extracting the phase angle of the grid voltage. So current controlled grid side VSI have to be implement with two cascaded loops.

i] Inner current loop to control the active and reactive components of current injected into the grid & so the control of power flow between grid & VSI. ii] Outer voltage loop which is used to balance the power flow in the system, in other words it balance the power flow by matching the phases of output current & grid voltage as unity.

B.HYBRID ENERGY CONNECTED WITH PI CONTROLLER USING PLL

Using PLL as shown in figure 2, voltage is sensed by Clarke and park transform and thus angle of voltage θ is determined.

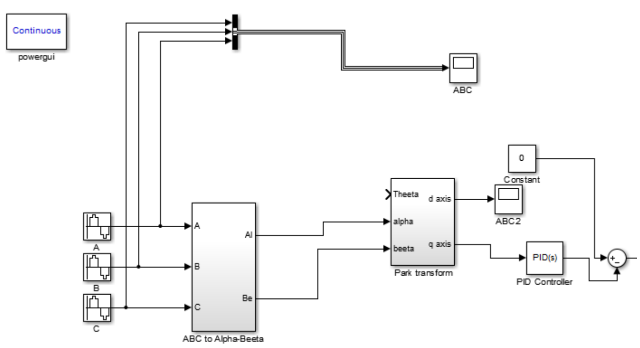


Fig. 2: Phase-Locked loop

PLL operation can be explained through the following steps:

Three phase grid voltage VRY, VYB, VBR are measured

$Uag = Ug\cos\theta$

$Ubg = Ug\cos(\theta - 2\pi/3)$

$Ucg = Ug\cos(\theta + 2\pi/3)$

Measured phase voltage are transformed to αβ stationary reference frame using Clarke transform

$$\begin{pmatrix} U\alpha g \\ U\beta g \end{pmatrix} = \frac{2}{3}\begin{pmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}\backslash 2 & -\sqrt{3}\backslash 2 \end{pmatrix}\begin{pmatrix} Uag \\ Ubg \\ Ucg \end{pmatrix}$$

Using park transform, αβ stationary reference frame voltage is converted to dq rotating, rotating reference frame voltage with estimated phase angle $\hat{\theta}$ from PLL output.

$$\begin{pmatrix} Udg \\ Uqg \end{pmatrix} = \begin{pmatrix} \cos\hat{\theta} & \sin\hat{\theta} \\ -\sin\hat{\theta} & \cos\hat{\theta} \end{pmatrix}\begin{pmatrix} U\alpha g \\ U\beta g \end{pmatrix}$$

After applying transformation, grid dq compare,

$Udg = Ug\cos(\theta - \hat{\theta})$

$Uqg = Ug\sin(\theta - \hat{\theta})$

When phase angle estimated by the PLL $(\hat{\theta})$ is same as the actual phase angle θ, then q-axis component in the rotating reference frame (Uqg) will be zero. If not, q-axis component is linearly proportional to error.

$Uqg \sim (\theta - \hat{\theta})$

This property is used to find the grid voltage phase angle. A low pass filter \PI is used to eliminate steady state error and the output fed to a VCO, which generates the angle and sine values.

1] The basic problems consist in designing a PLL circuit that can track accurately and continuously the positive sequence component at the find a method frequency and its phase angle, even when the system voltage of the bus to which the active power line conditioner is connected is distorted and / or unbalanced.

2] As line notching, voltage unbalance, line disputed, phase loss and frequency variations are common condition faced by equipment interfacing with electric grid. The PLL needs to be able to reject the source of error and maintain a clean phase lock to grid voltage.

3] Reference single obtained from the grid voltage is contaminated by harmonics, which may here been produce by the power converter itself or generated elsewhere. Additionally the voltage in a 3Φ system may contain unbalances from negative and/ or zero sequence component.

4] According to the mathematical model of the grid connected inverter the output voltage of the inverter in synchronous frame

$$\begin{pmatrix} Ud \\ Uq \end{pmatrix} = I\frac{d}{dx}\begin{pmatrix} id \\ iq \end{pmatrix} + R\begin{pmatrix} id \\ iq \end{pmatrix} + \omega L\begin{pmatrix} iq \\ id \end{pmatrix} + \begin{pmatrix} ed \\ eq \end{pmatrix}$$

4. RESULTS AND DISCUSSION

Current and Voltage are analysed with and without PI controller using PLL. The proposed method is designed in MAT Lab Simulink as is shown in fig 2.

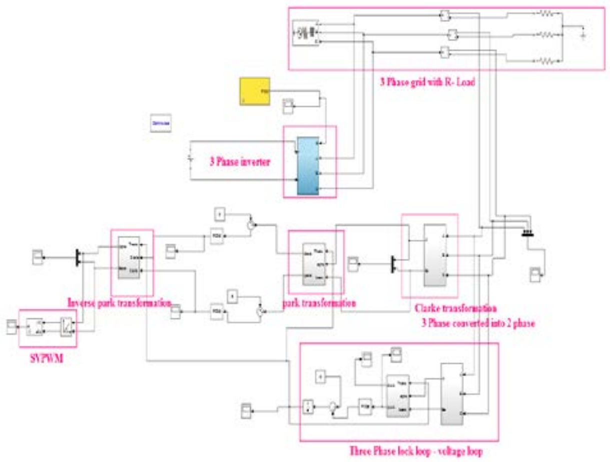


Fig. 3: Design of Hybrid energy using PLL with PI controller

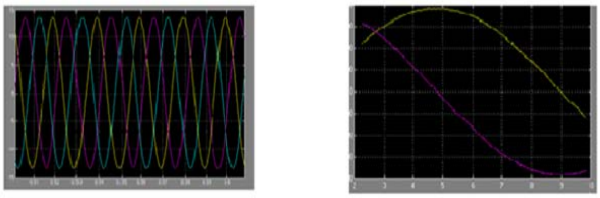


Fig. 4: Clarke Transform

Figure 4 shows the conversion of three phase current i_a, i_b *and* i_c into two phase i_α *and* i_β using Clarke transform.

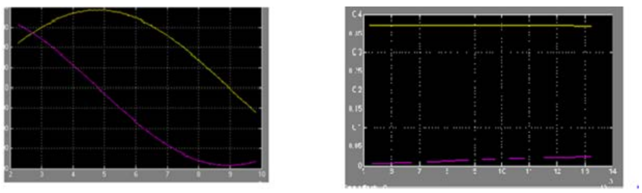


Fig. 5: Conversion of i_α *and* i_β into i_d *and* i_q using Park transforms.

The above figure 5 shows the conversion of current using park transform

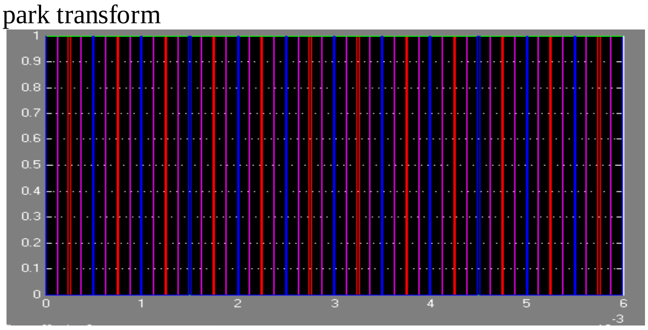


Fig. 6: Output waveform of Space Vector Modulation

The SVPWM relies on the representation of the output voltage the inverter output as space vector or space phasors. Space vector representation of the output voltages of the inverter is realized of the implemented in proposed method as shown in fig.6.

5. CONCLUSION

In this paper, wind and solar energy resources are utilized to generate power. If the generated power attains interruption the performance and efficiency may be degraded. To overcome the degradation PLL is employed and analysed by sensing the grid voltage and making the phase sequence of the inverter output voltage to match with the grid voltage. The system is designed using MATLab Simulink and the results are analysed with PI and without PI controller using PLL. The prototype was designed and the performance was predetermined successfully.

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