Synchronization Methods for Interconnection of a PEM Fuel Cell to the Utility Grid

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***Abstract* – There are various types of distributed energy systems available in the country which is more or less relevant to the climatic zones. These energy systems are primarily renewable energy sources. The power obtained from it are to be provided to utility grid. For this case, the main problem which is to be addressed is synchronization. Indeed, the synchronization consists of implementing a control strategy and electronic control of the interconnection to the grid for these type of energy sources. This is required to support the power system during an eventual power failure which is caused due to the various types of disturbances that may occur on the grid (amplitude variation, phase shift, harmonics and unbalanced load) in addition to supplying power under normal conditions. It is based on the rapid and accurate detection of the phase angle of the power grid voltage, which can be estimated using a phase locked loop (PLL). In this paper, we are presenting the PLL implementation and then doing a detailed analysis by examining its behavior under normal and special grid faults.**

***Keywords* – PEM Fuel cell, Grid, Converter, Inverter, Synchronization.**

I. INTRODUCTION

All renewable energy sources produce dc power. For connection with utility grid, a converter is required. These converters are polluting sources in terms of absorption of non-sinusoidal currents and particularly reactive currents. These harmonics are the disturbances which affects the waveform of the grid voltage. The other distortions that may occur in the mains voltage are the unbalance in the three-phase system, the frequency variation, the voltage dips and the phase jump. Phase jump and unbalance occurs when load or generator is connected or disconnected from the system. All these distortions and disturbances have the consequences of modifying the characteristics of the voltage wave or of the current which causes synchronization difficult.

To ensure a good connection of the fuel cell stacks with the electrical grid, the output voltage of the converter must have the same characteristic parameters for all of the three phases. For this to happen, a modulated signal (PWM) is created by the phase difference which is selected as the control signal for the PWM control system. This control system, managed by a microprocessor ensures that the characteristics of the current produced meets the requirements imposed by the network manager. This is necessary for the stability of the current, voltage, frequency, harmonic emission etc. and also ensures the safety of the system. This is a real time and permanent process for synchronizing the outputs of the inverters with those of the electrical grid. The most common technique used for phase lock system is the use of a phase locked loop (PLL) technique. Thus, in a first step, we are interested in the study and design of a PLL which is able to evaluate the phase angle of the voltage of a utility grid in a correct way. The identification of phase angle makes it possible to synchronize the fuel cell stack with respect to the utility grid.

II. PHASE LOCKED LOOP

Phase Locked Loop (PLL) are electronic devices to synchronize the phase of a local oscillator to that of an external signal. They are widely used in the process of information processing and data transmission. Particularly, in the case of fuel cell, to transmit the power successfully to grid, the matching of fuel cell inverter voltage in terms of its phase angle and frequency with that of the grid is essential.

III. GENERAL STRUCTURE OF PLL

A synchronous reference frame PLL is a basic type of phase-locked loop based on the park transformation. The objective of this PLL is then to minimize either the direct or quadrature axis reference voltage. This will then ensure that the phase angle of the rotating reference frame of the park transformation matches the phase angle of the utility grid voltage vector.

A voltage source inverter (VSI) is utilized to convert the DC power into AC power for supplying to the utility grid. The control of the inverter is done through synchronously rotating reference frame (SRF) method, which provides the decoupled control of active and reactive power fed to the grid. Here for the detection of grid phase angle, a 3-phase locked loop (PLL) is used which also works on the principle of SRF.

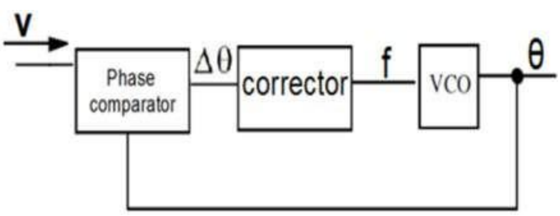

Figure1. Basic Block diagram of a PLL

A basic type of PLL contains three basic components: a phase comparator, a corrector and an oscillator or voltage-controlled oscillator. The main purpose of the advanced techniques used in PLL technology is to use a robust phase tracking of the grid to overcome the existence of disturbances.

In this type of PLL configuration, we assume that the network voltages are balanced and used as inputs to the PLL and its output corresponds to the phase angle of one of the three phases. Once this is detected, we make a shift of 120 degrees for each of the other three phases.

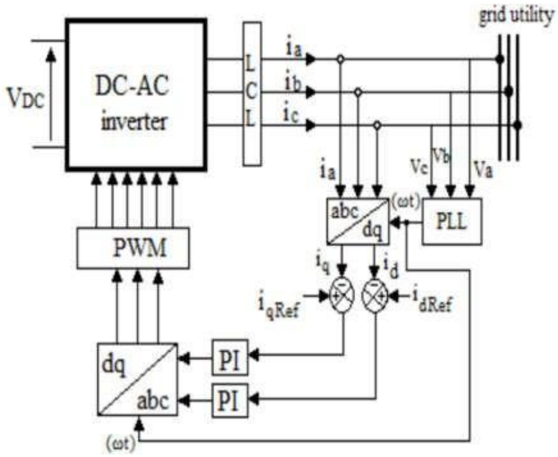

Figure 2. PLL Implementation

The proposed control consists in applying the dq0 transformation for the line phase currents. The dqo transformation allows transforming a balanced three-phase system to an equivalent two-axis representation, thus it considerably simplifies the calculations and control. In the dqo rotating reference frame, the active power and the reactive power at steady state are given respectively by

$$= \frac{3}{2}$$

$$Q = -\frac{3}{2} V_d I_q$$

Where is the current quadrature axis component, is the direct axis component current and is the direct axis component voltage.

Therefore, the control of the active power is done by controlling ( ) while the control of the reactive power is done by controlling ( ). The advantage of this control is the fact that the control of the active power is decoupled from the control of the reactive power. The error between the actual values and the reference values of and currents are introduced to PI controllers. The PI outputs must undergo a dqo reverse transformation in order to have vector control in the natural three-phase reference frame. The obtained three signals are compared with a high frequency triangular signal to generate the PWM signals.

Synchronously rotating reference frame control (d-q control) method

Here, the components of grid currents and voltages are taken along two fictitious orthogonal d-q axes which rotate at the same synchronous speed as grid frequency. Therefore, it is also called d-q control method.

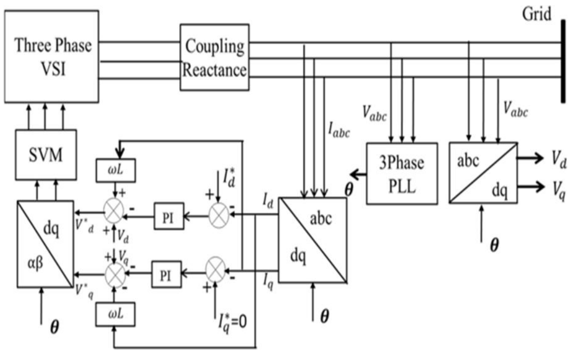

Figure 3. Block diagram of inverter controller for d-q control

In the above figure, the grid currents , and and grid phase voltages , and are transformed into DC variables and and and respectively through axes transformation method. The control variables and have DC values so the conventional PI controllers are suitable to control them. During this transformation the detection of grid phase voltage angle ( ) and frequency (f) are required.

Here, the synchronous rotating reference frame (SRF) based 3-phase phase locked loop (PLL) is used for phase detection of the grid voltage. The block diagram model of 3-phase SRF based PLL is as given in figure 4. The expression of and during the tracking of grid voltage phase angle is given in equation.

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} V_m \cos(\theta - \theta^*) \\ V \ \sin(\theta - \theta^*) \end{bmatrix}$$

Where : Peak value of grid phase to ground voltage

= Phase angle of grid phase to ground voltage

θ^* = Tracking angle of PLL

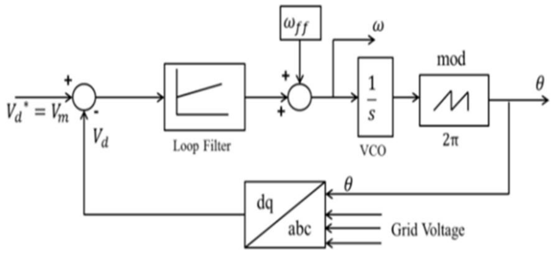

Figure 4. Block diagram of 3-phase SRF based PLL

The error between reference $V^* = V_m$ and measured V_d is passed through loop filter which is a PI regulator and voltage control oscillator which works as an integrator. As feed-forward frequency ω_{ff} is added to the output of loop filter, it improves the initial dynamic response of PLL system and prevents the output signal θ that goes to zero. In the present system the feed-forward frequency will be $2\pi f = 100\pi$. In equation when V_d equals V_m then θ and θ^*coincide each other and grid phase angle is tracked.

Active and reactive power control

The active and reactive power P and Q fed to the grid in the d-q frame are given in equations below:

$$= \frac{3}{2}[\quad + \quad]$$

$$Q = \frac{3}{2}[V_q I_d - V_d I_q]$$

Where , , and are phase to ground grid voltage and inverter to grid current in d-q frame. In the case of unity power factor operation = , = 0.Thus the reference value of I^* and I^* can be calculated by reference value of active and reactive power P^* and Q^* as given in equations below:

$$I^* = \frac{2P^*}{3}$$

$$I^* = -\frac{2Q^*}{3} = 0$$

For $Q^* = 0$

IV. CONCLUSION

A proton exchange membrane fuel cell-based supply system for electrical grid is analysed and discussed. In the presented inverter control method, the grid phase angle detection is also performed using SRF (d-q control) method which is same as was used for inverter controller. It guarantees the compactness of the whole system and make it more economical. The decoupling of d-q axis is done which accelerates the performance of inverter. The PI controller is used for controlling the duty cycle in order to get the desired AC voltage that would feed the grid through inverter. In this paper, a PWM-PI current control is proposed for a fuel cell grid connected system. It offers a good steady-state response, fast dynamic response, and highly sinusoidal injected current waveform with very low current ripple. The proposed model will be used for studies on fuel cell systems under grid faults.

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