A Synchronization Method of Proton Exchange Membrane Fuel Cell with Utility Grid

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Abstract

Fuel cell is a promising renewable energy source alternative for fossil fuel, used for electricity generation. Conventionally, a coal based thermal power plants are used for generating power. This requires, power plants to be synchronized with grid in terms of voltage and frequency. The main limitation in using coal based power plants are greenhouse gas emission which causes global warming. Fuel cell based power generation is clean and green. It uses hydrogen as a fuel which in turn is obtained from water by reverse electrolysis which is also green. The main issue is synchronization of fuel cell with grid in terms of grid voltage and frequency which is being addressed here. For synchronization, we need power conditioning units apart from fuel cell. A proton exchange membrane fuel cell (PEMFC) has been mostly used for power generation and the same has been discussed in this paper. Another issue is unstable voltage output as the load is increased. In this context, the techniques mentioned in previous literature, used for synchronization of fuel cell with grid has been reviewed. A brief description of the method used for synchronization is also mentioned here. Finally the results and conclusions are drawn at the end of the research paper.

1. Introduction

A fuel cell is an electrochemical cell that converts the chemical energy of the fuel generally hydrogen and an oxidizing agent generally oxygen into electricity by the pair of chemical reactions. However, a stand-alone fuel cell can also be brought to use, but if it is synchronized with utility grid, then its purpose will be justified. It can supply the power when the load is increased on the grid side. When we can obtain the additional power from the fuel cell, then there is no need of grid upgradation when the consumer base is increased. This requires fuel cell to be synchronized fully. For that, we need an accurate modelling of fuel cell. Accurate fuel cell models are required to predict and evaluate their steady state and dynamic responses as suggested in [1]. Fuel cell can be modelled considering the partial pressures of hydrogen and oxygen at their respective electrode. The nernst potential equation is used to model a fuel cell which is a theoretical thermodynamic potential of a single fuel cell at 25^0 C and at 1 atm and is of the order of 1.229 V [2]. A theoretical as well as numerical model is developed for better understanding of the effect of operating conditions and cell design on the fuel cell performance for better synchronization [3]. It has been found that PEM fuel cell output voltage is very low for direct connection to grid. Thus a boost converter is usually required to step up the input voltage to the desired output voltage [4]. A Pulse Width Modulation (PWM) voltage source inverter (VSI) with low loss and high frequency IGBT switches, is used to connect the FC system to the utility grid for real and reactive power control purposes [5]. It also suggested a low pass filter which is a low pass LC type, connected at the output of the inverter to provide a sinusoidal output voltage. This filter is of higher current rating as dictated by the load circuit. Finally, a general method for fuel cell integration with grid is discussed in this paper. The research areas which needs to be explored apart from the existing research has been suggested in this paper. At last, a conclusion is drawn from the discussion made.

2. Methodology

A fuel cell generates a high direct current under a low voltage as can be seen in Fig I. This has prompted researchers to focus on power electronics associated with their integration to the grid.

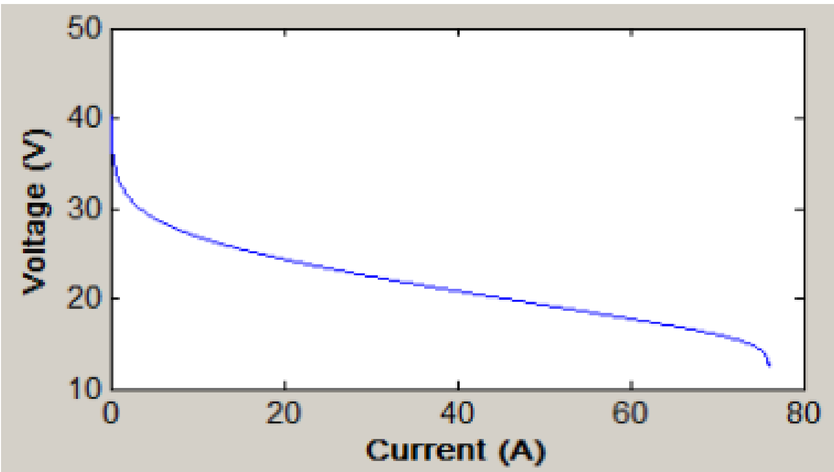

Fig 1. Polarisation Curve of a PEM Fuel Cell Stack.

As we can see from the figure, that as the current density is increased, the output voltage of the fuel cell starts decreasing. The initial decline in output voltage is due to the activation polarization or activation loss occurred during the initial operation of the fuel cell. The tail end of the curve which sees the sharp decline in voltage is due to the concentration polarization loss which reduces the gas diffusion efficiency of the fuel cell [6]. The middle part of the curve is nearly flat, which is due to the ohmic polarization loss occurring across the membrane, electrodes as well as in the external circuit. The is the region where fuel cell is intended to operate. Thus, linear portion of the curve is the normal operating point of the fuel cell. As the output voltage is like drooping characteristic, we need power conditioning unit to boost the voltage to the desired level. The boost converter is used for this purpose which is connected after the fuel cell unit. Since the output voltage of the boost converter is dc type, we need inverter to invert it into ac, so that it can be synchronized with ac grid. The inverter used are three-phase six switch voltage source inverter (VSI) to be connected to the utility grid. As power semiconductor devices are used, harmonics are likely to be induced in the circuit. To mitigate the harmonics, low pass LC filter are connected after the inverter. Since the voltage produced are low level, a step up transformer can be introduced after the filter circuit to bring it up to the level of grid voltage level [7].

The control is done via a loop that controls the active power and the reactive power of the grid injected current. The injected power control to the grid is mainly done by controlling the inverter switch. The proposed control consists in applying the dq0 transformation for the line phase currents [8]. The dq0 transformation allows transforming a balanced three-phase system to an equivalent two-axis representation, thus, it considerably simplifies the calculations and the control. In the dq0 rotating reference frame, the active power and the reactive power at steady state are given respectively by the following equations:

$P = \frac{3}{2} V_d I_d$ ………………… (1)

$Q = -\frac{3}{2} V_d I_q$ …………………….. (2)

where i_q is the current quadrature axis component, i_d is the direct axis component current and V_d is the direct axis component voltage [9]. Therefore the control of the active power is done by controlling (I_d) while the control of the reactive power is done by controlling (I_q). 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 I_q and I_d currents are introduced to PI controllers. The PI outputs must undergo a dq0 reverse transformation in order to have vector control in the natural three-phase reference frame [10]. The obtained three signals are compared with a high frequency triangular signal to generate the PWM signals for the inverter control as shown in Fig.II.

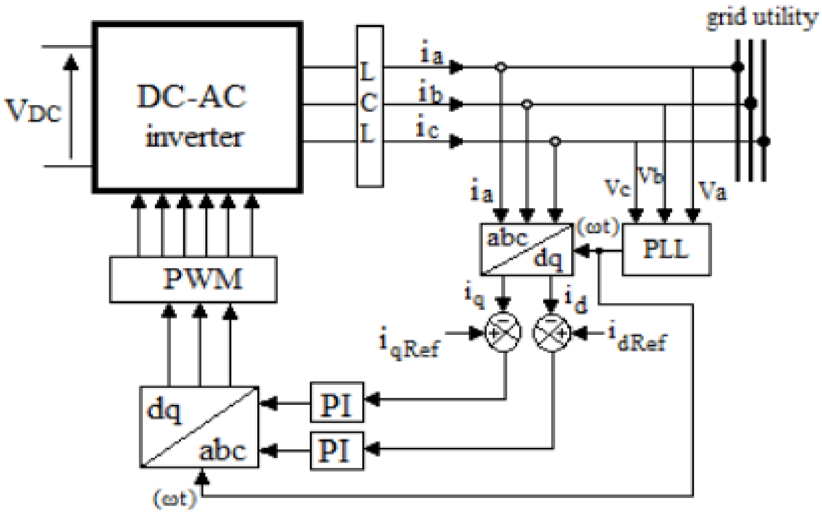

Fig 2. Inverter Control

The proposed control is firstly tested in the case where operation at a unit power factor (PF = 1) is desired. For this reason, it required to impose a zero set point to the injected reactive power (i_{qref} = 0). In this case, the three-phase output currents of the inverter and the mains voltages of the grid are synchronized. Finally, the proposed control was tested in the case of abrupt changes of active and reactive power demand of the grid. It has been found that the proposed control adjusts the active power and reactive power output of the inverter as demanded by the grid. When, the inverter output power matches with the required power of the grid, then we can say that the grid is synchronized with the fuel cell [11]. Here, the grid is synchronized with the inverter considering the reactive power requirement to be zero.

3. Result and Discussion

Synchronization is an important aspect of fuel cell connected to grid. Without it, the fuel cell cannot deliver power successfully to grid. It is known that, the output power of the inverter consists of active as well as reactive power. Active power is dependent on phase angle and is controlled by adjusting the phase angle between mains voltage and the inverter voltage while the reactive power is controlled by adjusting the voltage magnitude. For unity power factor operation, reactive power is fed locally, instead of drawing it from distributed generation source. The phase angle between the mains and the inverter is controlled by using phase locked loop (PLL). It tunes the phase angle between the two in such a way that exact power is met from the inverter side as demanded by the grid. The output power is adjusted by a PI controller which is fed by the difference of the reference value of the active and reactive power and its actual value. Here, the dqo transformation is used for controlling the power. The dqo transformation decouples the active and reactive power control from each other.

4. Conclusion

This paper deals with the particular mechanism used to synchronize the distributed generation systems esp. fuel cell with grid. Synchronization is achieved by controlling the inverter. The control is done via two loops: a loop that regulates the DC voltage at the inverter input and a loop that controls the active and reactive power of the grid injected current. Also, the phase angle synchronization between the fuel cell and grid is achieved by using phase locked loop (PLL). The control is implemented by using PI controller. The dqo transformation is being used to simplify the control as shown in fig II Thus this mechanism synchronizes the active and reactive power generation of the fuel cell via inverter with that of grid power.

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