International Journal of Engineering Research
Volume No.4, Issue No.10, pp : 523-526

ISSN:2319-6890)(online),2347-5013(print)
01 Oct. 2015

PQ Control Based Grid Connected DG Systems

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Abstract: Distributed generation (DG) generally refer to small scale electric power generators produce electricity that is bound to an electric distribution system. Distributed generation systems such as photovoltaic (PV) or wind energy systems are parts of the future smart grids. By applying intelligent techniques these future grids change as smarter grids. During the past few years electrical energy consumption to the investment is increased when compared to cost on transmission and distribution resulting in compromised reliability and high energy costs. So there is need to change from conventional grid to smart grid. Micro grids consist of small power sources called distributed generation system. Many distributed generation systems such as photovoltaic systems are grid interfaced through power electronic voltage source inverters.

In this paper a boost inverter technique is explained and distributed generation sources such as PV and fuel cell are connected in series with the help of PQ controller technique the above system is evaluated.

Keywords: PQ controller, Distributed Generation systems, Boost inverter

I. INTRODUCTION

Electrical energy consumption has grown high in the recent years and investment towards transmission and distribution system has decreased constantly. Therefore the grid is under stress with compromised reliability and the cost of energy is increasing. So there is need to explain the necessary of future smart grids. This future smart grid will be a platform to make possible the coexistence of smart self controlling micro grids.

Energy systems based on photovoltaic and fuel cells need to be commissioned at both ac and dc loads. These DG systems are taken from renewable sources such as wind turbines, photovoltaic panels, fuel cells, combustion gas turbines etc. These micro grids have power levels from sub KWs to MWs. Micro grids can operate both in independently or connected to main distribution grid. Most of the modern distributed systems such as photovoltaic systems are grid interfaced through power electronic sources. The entire system consists of power electronic conversion system technologies and energy storage unit to supply high quality power. Power conditioning of photovoltaic cells have undergone various changes in the recent years to keep some pace in the emerging technologies and fuel cells are emerging as an attractive power supply source because they are highly efficient and reliable. In the recent years they are used in many applications such as distributed generation systems and electric vehicles.

This paper discusses about the modeling photovoltaic cell and fuel cell. A boost inverter technique is explained in this paper with a back-up energy storage system. Here PQ controller is used by the boost inverter system during the grid connection mode.

II. MODELLING OF PROPOSED SYSTEM

A. *Equivalent circuit of PV cell*

Photovoltaic is a method of converting solar energy into direct current electricity using semiconductor materials that exhibit photovoltaic effect. The generated current differs linearly with the solar irradiance.

A typical solar cell produces about 0.5-.06V DC current under open circuit no load conditions. The current output of a photovoltaic cell depends on its efficiency size and proportional to intensity of sunlight striking the surface of the cell.

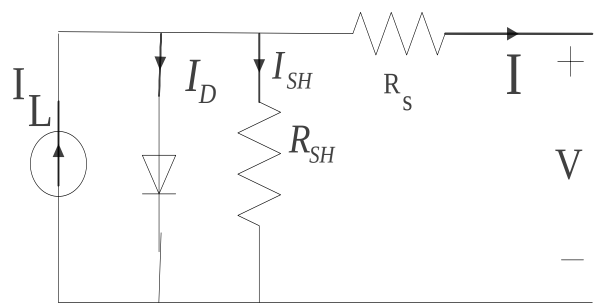

Fig.1Equivalent circuit of PV cell.

B. *Mathematical equations*

$$I_{ph} - I_D - I_{sh} = I_L$$

$$I_{ph} - I_0\left(e^{\frac{qV_D}{\gamma kt}} - 1\right) - \frac{V_D}{R_{sh}} = I_L$$

$$I_{ph} - I_0(e^{AV_D} - 1) - \frac{V_D}{R_{sh}} = I_L$$

Where A= q/γkt

$$I_{ph} - I_0\left(e^{A(V_L + I_L R_S)} - 1\right) - \frac{V_L + I_L R_S}{R_{sh}} = I_L \qquad 1$$

From above equation

$$I_{ph} - \frac{V_L + I_L R_S}{R_{sh}} - I_L = I_0(e^{A(V_L + I_L R_S)} - 1)$$

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$$\frac{I_{ph}}{I_0} - \frac{V_L + I_L}{R_{sh} I_0} - \frac{I_L}{I_0} = e^{A(V_L + I_L R_S)} - 1$$

$$\frac{I_{ph}}{I_0} - \frac{V_L + I_L R_S}{R_{sh} I_0} - \frac{I_L}{I_0} + 1 = e^{A(V_L + I_L R_S)}$$

Applying logarithm on both sides

$$AV_L + AI_L R_S = \ln[\frac{I_{ph}}{I_0} - \frac{V_L + I_L R_S}{R_{sh} I_0} - \frac{I_L}{I_0} + 1]$$

$$V_L = \frac{1}{A}\ln[\frac{I_{ph}}{I_0} - \frac{V_L + I_L R_S}{R_{sh} I_0} - \frac{I_L}{I_0} + 1] - I_L R_S \qquad 2$$

C. Maximum power point technique

Maximum power point tracking is a technique that grid connected inverters solar battery charges and similar devices use to get the maximum possible power from one or more photovoltaic devices. A regular solar panel converts only 30 to 40 percent of the observed solar radiation into electrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel.

The different types of techniques used to track the maximum power point are as follows:

1) Perturb and observe method
2) Incremental conductance method
3) Fractional short circuit current
4) Fractional open circuit voltage
5) Neural networks
6) Fuzzy logic

In the following techniques most commonly used technique is perturb and observe method also called as hill climbing method.

Perturb and observe method is the simple method. In this we use only one sensor that is voltage sensor used to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to the MPP it doesn't stop at the MPP and keeps on perturbing in both directions. When this happens the algorithm has reached very close to the MPP and we can set an appropriate error limit.

D. Equivalent circuit of fuel cell

Fuel cells have been called as the microchip of hydrogen age. A fuel cell is an electrochemical energy conversion device that converts into electricity by combining with oxygen and hydrogen. These fuel cells are cost effective for electric power generation due to their efficiency and cleanness. Their silent operation and measurability make them particularly attractive for distributed generation applications. Some of the difficulties that are facing by the fuel cells are improving efficiency, reducing system cost and equipment cost, and increasing reliability and life time of the entire system.

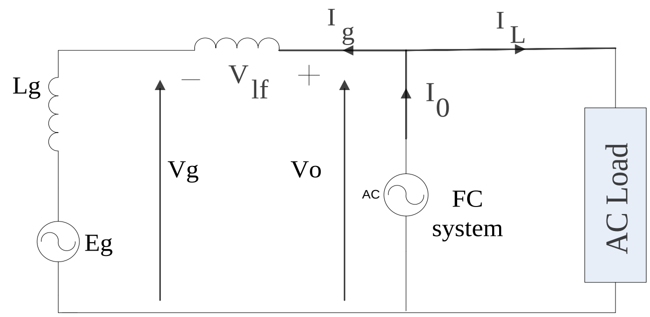

Fig.2 Equivalent circuit of grid connected FC system

Here the proposed single fuel cell grid connected system operates in two modes that is in grid connected mode or in standalone mode. A single stage boost inverter system is proposed which is suitable for both ac sources and also used to power the dc sources is able to boost and invert the voltage at same time. Here the proposed FC is a 72-cell PMFC-proton exchange membrane fuel cell is used for which the voltage varies between 39-69V and the output power is about 1KW.

E. Boost inverter

Control method used in the proposed boost inverter is the name itself it specifies that the system can perform both boost up and also inversion of voltage in the same circuit. The boost inverter consists of a two bidirectional boost converters, each converter generates a dc biased sinusoidal output. The converter generates a unipolar voltage that is greater than the fuel cell voltage. Here from the obtained output voltage it can be observed that V_0 contains only ac component.

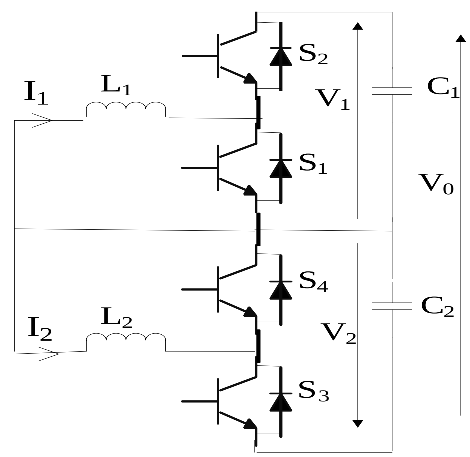

Fig.3 Boost Inverter

$$V_1 = V_{dc} + 1/2\ X_1 \sin\theta \qquad 3$$
$$V_2 = V_{dc} + 1/2\ X_2 \sin(\theta\text{-}\pi) \qquad 4$$
$$V_0 = V_1 - V_2 = A_0 \sin\theta \qquad 5$$
When $X_0 = X_1 = X_2$
$$V_{dc} > V_{in} + A_0 / 2 \qquad 6$$

Where V_{dc} is the dc offset voltage of each boost converter

The reference voltage of the boost inverter is taken from the PQ control algorithm is able to control the active and reactive power. The voltage across capacitors C_1 and C_2 are controlled to

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track the voltage references using proportional resonant controllers. The current through L_1 and L_2 are controlled by proportional resonant controllers to achieve stable operation.

F. Backup energy storage unit

The name itself suggests that the storage device helps us in backing up if there is any delay in the supply of power to the system. In this proposed system backup energy storage unit is used for us in two ways the first is designed to protect the slow dynamics of the fuel cell system and the second is to protect the fuel cell system. The backup system provides low frequency ac current that is required for the operation of the boost inverter.

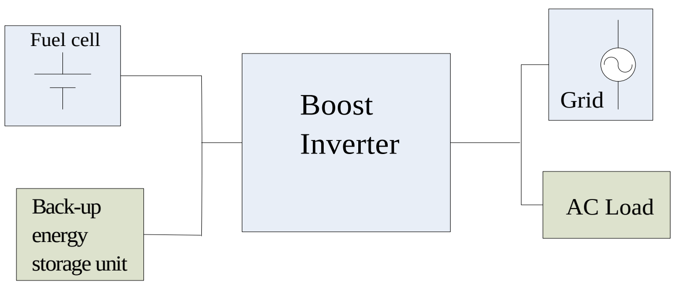

Fig.4 Block diagram for the proposed grid connected fuel cell system

The backup unit consists of a current mode converter and a battery as a energy storage device. When the load is disconnected from the circuit the excess power from the fuel cell is stored in the backup unit.

III. DESIGN OF PQ CONTROLLER

In this paper, a PQ controller is designed so that in grid connected mode the boost inverter is able to control the active and reactive power system. The main concept of the PQ control is the use of grid capable frequency and voltage drops. From that fact the active and reactive powers are controlled by small signal variations of voltage phase and magnitude.

Here in PQ control P^* and Q^* are the two individual components in which voltage difference is derived from P^* and from Q^* the phase shift δ is obtained. The δ component from Q^* and ω_0 component from the P^* are combined together to form the reference voltage V_0 which is given as input to the boost inverter.

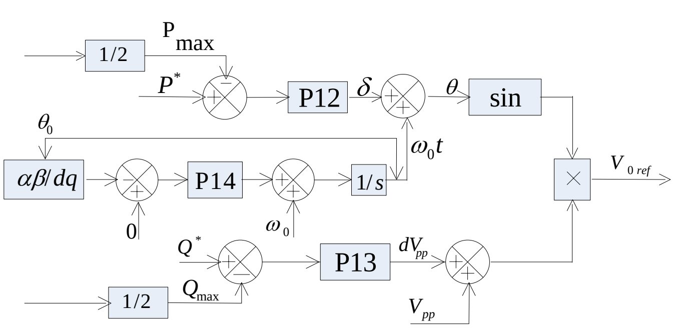

Fig.5 PQ Control Topology

The overall block diagram of the proposed grid connected DG systems is shown in the figure below. In this system a photovoltaic system and a fuel cell system are connected is series and the output from both the systems are given to the boost inverter circuit. Here by using boost inverter the output voltage is boosted and inverted in the same circuit as explained. From then it is given to grid or the load that is connected to the circuit. The reference voltage of the boost inverter is provided from the PQ controller that is used to control both the active and reactive power. The voltage across the capacitors and the currents through the inductors are controlled by the proportional resonant controllers.

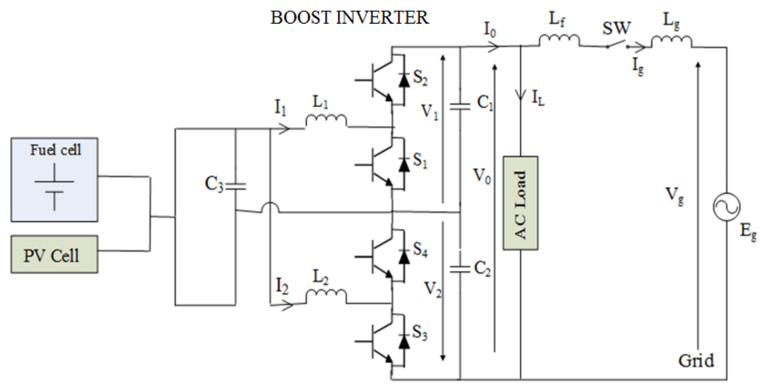

Fig.6 Block diagram for the proposed grid connected DG system

Through the P reference we produce frequency and by Q reference voltage magnitude is generated by combining both we generate reference voltage V_0. This generated voltage is given as input to the boost inverter. By calculating all the power losses and controller voltage from the PR controller and by using repeating sequence pulses are generated. These generated pulses are given to load.

IV. SIMULATION RESULTS

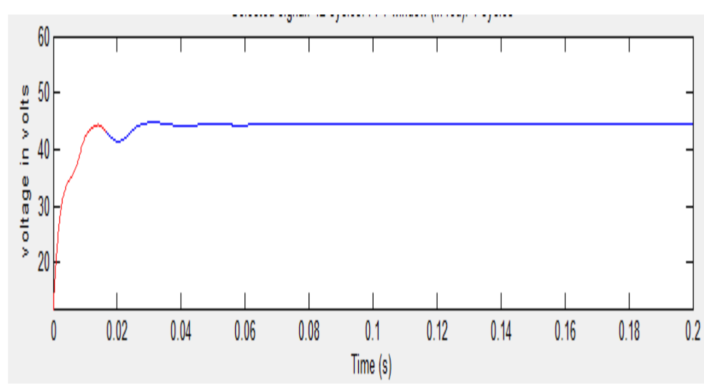

Fig.7 PV cell output voltage

The input voltage given to one PV cell is around 0.5V in this manner total ninety cells are connected and the obtained voltage is 45V.

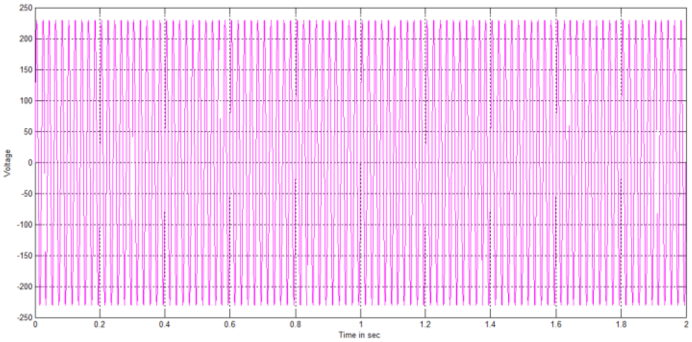

Fig.8 Output voltage of the grid

Grid voltage is considered as 230V and boosted voltage is obtained around 230V.

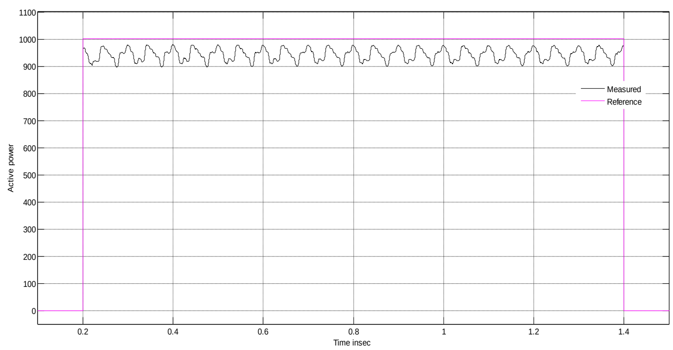

Fig.9 Active power measurement and reference

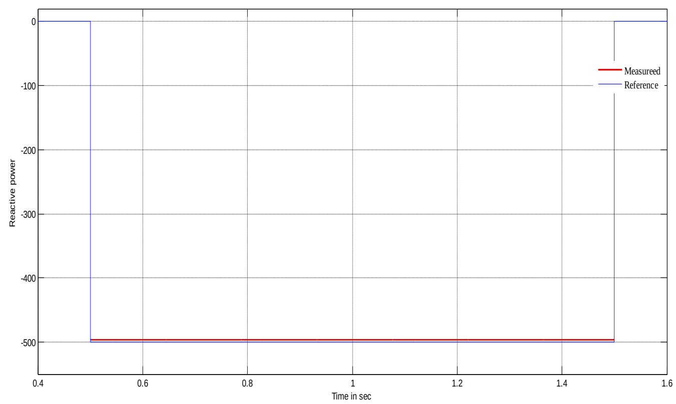

Fig.10 Reactive power measurement and reference

The active and reactive powers of PQ controllers are as follows. The pink line indicates reference and the black line indicates the calculated value. The P control reference value is ranging at 1000 and obtained value is at 997. In the same way the reactive power calculated value is 497.3 and the reference value is 500. The respected outputs are shown above.

V. CONCLUSION

A single phase grid connected fuel cell system and a PV based system with boost inverter topology with backup energy storage is explained in this paper. The proposed system has a single power conversion stage with high efficiency and able to operate in standalone system as well as in grid connected mode. By connecting diode bridge wind energy system can also be interconnected with the above system this helps in eliminating the use of complex cycloconverters.

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