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Fuel Cell Based Single Phase Pure Sine Wave Inverter with PI *controller*

Reena Soni
M.Tech Scholar, NIIST Bhopal, India
Paramjeet Kaur
Professor, NIIST Bhopal, India

Abstract:
Renewable energy plays an important role in our life over last few years. As we seen that cost of electricity and their resources day by day increasing. Fuel cell is the best way to fulfill the requirement of energy. It is a clean, efficient and pollution free source of energy. In this paper modeling and simulation of fuel cell based single phase inverter with PI controller is presented. Fuel cell based power supply needs a power conditioner which convert dc output voltage of the fuel cell which is very low into usable ac voltage, sufficient for residential applications. Power conditioner is a combination of DC-DC full bridge boost converter and inverter. Full bridge boost converter step up the output of fuel cell (24V) to regulated high voltage(400V) and inverter converts this voltage to pure sinusoidal 220V,50Hz AC voltage. Sine Pulse width Modulation(SPWM) technique for controlling of boost converter and PI controller used for controlling of inverter.

Keywords*: Fuel cell, Full Bridge DC-DC boost converter, Full bridge inverter, PI controller*

1. Introduction
Fuel cell are an important enabling technology for the nation's energy portfolio and have the potential to revolutionize the way we power our nation, offering cleaner, more efficient alternatives to the combustion of gasoline and other fossil fuels. Fuel cells have the potential to replace the energy sources because they are energy efficient, clean and reliable services [1]. In order to effective use of fuel cell a power conditioner is needed which convert the output voltage of fuel cell into usable AC voltage. Power conditioning for fuel cell is an important area of research in order to generate a large amount of electricity.

2. Fuel Cell
Fuel cells cleanly and efficiently convert chemical energy from hydrogen-rich fuels into electrical power and usable high quality heat in an electrochemical process that is virtually absent of pollutants. Similar to a battery, a fuel cell is comprised of many individual cells that are grouped together to form a fuel cell stack. Each individual cell contains an anode, a cathode and an electrolyte layer. When a hydrogen-rich fuel such as clean natural gas or renewable biogas enters the fuel cell stack, it reacts electrochemically with oxygen (i.e. ambient air) to produce electric current, heat and water. While a typical battery has a fixed supply of energy, fuel cells continuously generate electricity as long as fuel is supplied. Individual fuel cell produce relatively small electric potential, about 0.7V to 1.2V. So cells are stacked, or placed in series, to increase the voltage and meet the requirements [2-3]. According to the chemical characteristics of the fuel used in fuel cell, they are classified as:

- Alkaline Fuel Cell (AFC)
- Phosphoric acid Fuel Cell (PAFC)
- Proton Exchange Membrane Fuel Cell (PEMFC)
- Molten Carbonate Fuel cell (MCFC)
- Solid Oxide Fuel Cell (SOFC)

A simplified operation of PEMFC as shown in the fig.

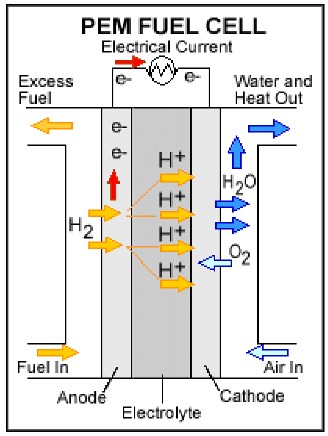

Figure 1

Proton exchange Membrane (PEM) fuel cells, also known as Polymer exchange membrane fuel cells typically operate on pure (99.999%) hydrogen fuel. The PEM fuel cell combines the hydrogen fuel with the oxygen from the atmosphere to produce Water, heat (up to 90°C) and electricity. PEM Fuel cells typically utilize platinum based catalyst on the anode to split the hydrogen into positive ions (protons) and negative electrons. The ions pass through the membrane to the cathode to combine with oxygen to produce water. The electrons must pass round an external circuit creating a current to rejoin the H2 ion on the cathode. Chemical Equation:

Anode: $2H_2$ »»$4H^+$ $+4e^-$

Cathode: $O_2 + 4H^+ + 4e^-$ »» $2H_2O$

Each cell produces approximately 1.2 volts, so to reach the required voltage the cells are combined to produce stacks. Each cell is divided with bipolar plates which while separating them provide a hydrogen fuel distribution channel, as well as a method of extracting the current.PEM fuel cells are considered to have the highest energy density of all the fuel cells, and due to the nature of the reaction have the quickest start up time (less than 1 sec) so they have been favored for applications such as vehicles, portable power and backup power applications. A single fuel cell produce very small voltage about 0.7V to 1.2V, therefore for power generation many fuel cells are connected in series arranging a stack. Most of the fuel cell stack modules produce low voltage in the range of 24-150Vdc.

The V-I characteristics single fuel cell as shown in the figure 2.

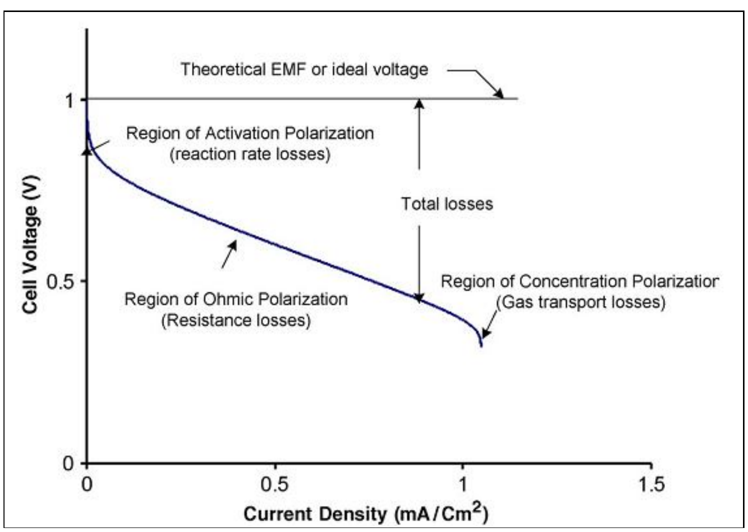

Figure 2

Output voltage of the fuel cell depend upon load and three additional losses:

- Activation loss
- Ohmic loss

- Concentration loss

There are some disadvantages of fuel cell are:

- Low output
- Large voltage variation with variation in load
- Slow dynamic response

To overcome all these problems we need a power conditioner for power generation from fuel cell.

3. Power Conditioning Unit

Power conditioning is the necessary technology for converting the output dc voltage of fuel cell into usable ac voltage. It is a combination of DC-DC full bridge boost converter and a single phase full bridge inverter.

3.1. DC-DC boost converter

As we know that fuel cell generates very low dc voltage (26V) which largely depends upon load variation. Full bridge boost converter converts this low voltage into high dc voltage (400V). Sinusoidal pulse width modulation (SPWM) technique used to generate control signal for full bridge boost converter which gives regulated high voltage. For switching of the converter unipolar SPWM technique is used. Unipolar technique reduces harmonic content of output voltage waveform than the bipolar technique. Boost converter convert the output voltage of the fuel cell into regulated high voltage (400Vdc) then fed to the inverter. Single phase inverter convert this voltage into usable ac voltage (220VAC, 50Hz) suitable for residential application and gives pure sine wave[4].

3.2. DC-AC Inverter

Single phase full bridge inverter is used for power generation. This is a very appropriate technology and fulfills the fuel cell requirements. Full bridge inverter converts this dc voltage into usable ac voltage, suitable for residential applications.

In this power conditioning scheme, we design a close loop system with PI controller for controlling of inverter. PI controller reduces the steady state error and improves the performance of the system. It is a combination of two actions:

- Proportional term: This term produce output value proportional to the current error value. Response of the proportional term can be adjusted by multiplying the error by constant Kp, called proportional gain constant.

Pout (S)= Kp E(S)

Large value of Kp produces large change in output for a given value of error. If the value of Kp is high then the system becomes unstable. Therefore the value of Kp should be as small as possible.

- Integral term: The integral term is proportional to magnitude and duration of the error.

I out(S)= Ki/S E(S)

The value of the Ki should be as high as possible to reduce steady state error.

PI controller gain is determine by

G(s)= Kp + Ki/S

Where, Kp = Proportional gain

Ki = Integral gain

PI controller improves the overall performance of system and increase the overall efficiency. This makes the system response relatively insensitive to external disturbances and internal variation in system parameters such as load variation. Now the output voltage of inverter becomes constant with load variation.

3.2.1. Power conditioner parameter selection

In order to generate single phase 220V, 50Hz pure sine wave for domestic application, the parameters used in power conditioning system should be properly selected. Power conditioner design parameters as given in the table

Parameters	**Value**
Fuel cell(FC)	24V,1.2KW PEMFC
DC Bus	400V
Output power, Po	1KW
Output voltage, Vo	220V,50Hz
Input inductance, Lin	10uH
Input capacitance, Cin	120mF
Switching frequency of converter	30KHz
Transformer turn ratio	1:14
Filter inductance, Lf	.09H
Filter capacitance, Cf	150uF
Load Resistance, R	60ohm
Switching frequency of inverter	30KHz
Proportional gain, Kp	1
Integral gain , Ki	1

Table 1: Power conditioner parameters specification

3.2.2..Simulink Diagram

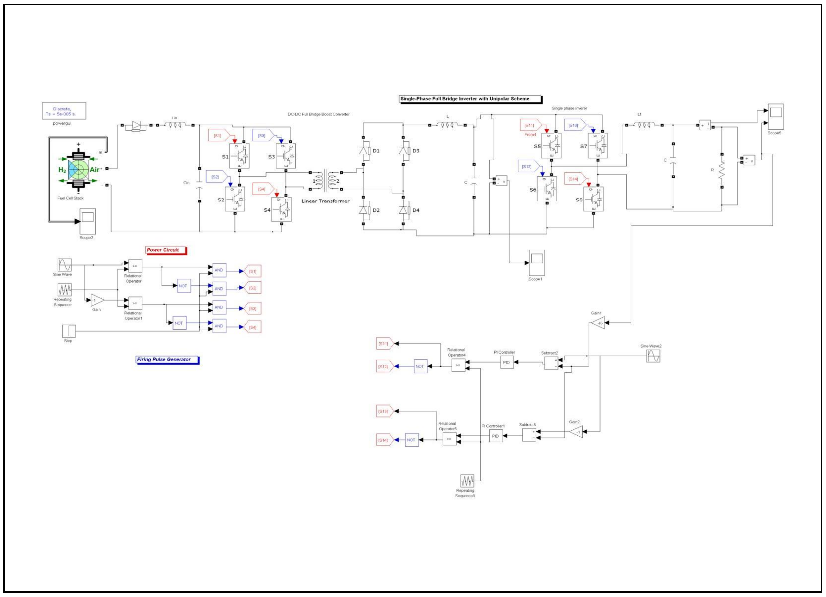

Figure 3

3.2.3..Simulation Result

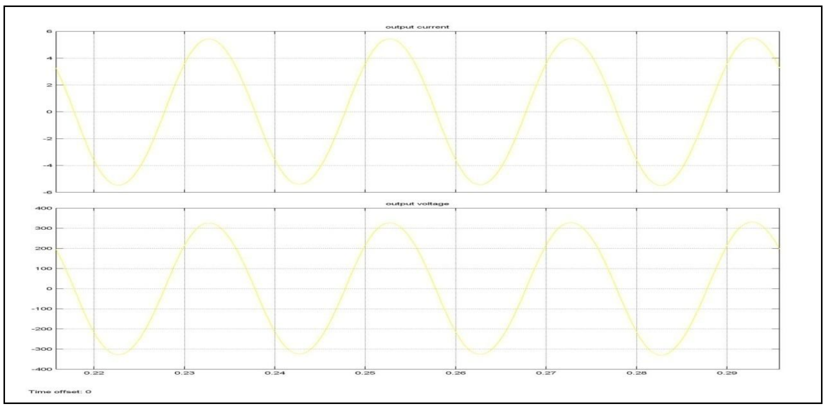

Figure 4

4. Conclusion

Fuel cell is a very promising source of renewable energy. In this paper we are presented two stage power conversions with close loop system and power conditioner suited for fuel cell power supply system discussed which gives 220V, 50Hz pure sinusoidal wave. Output voltage of inverter becomes independent of load variation. Close loop system with PI controller gives the better performance and increase the efficiency of overall system.

5. References

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