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Modeling of Fuel Cell Connected Distribution Generation System

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ABSTRACT*:* Power system plays important role for the generation of power from conventional sources, transmutation and distribution power at different consumer applications it will faces a so many problems. This can be overcome to implement the power is generated from the renewable energy sources like P.V Wind, Fuel cell, Micro Turbine etc will give signifying moment in near future. In this paper power generated by using fuel cell system because power is generated from P.V system under cloud& rain session it is impossible and power generation of wind energy system is also difficult under summer session is also difficult under these conductions interruption power occurs at consumer applications this can be overcome to in this paper power generated from fuel cell system. Fuel cells are known for their reliability, power quality, eco-friendly nature and fuel efficiency. Its promising technology and extremely significant in the near future. A voltage source inverter controller is developed for conversion of SOFC generation into ac grid system. The designed controller is also implemented to analyzed the output response of the developed fuel cell that can be used in distributed generation applications. The simulation results are presented based on MATLAB simulink.
Keywords: Fuel Cell power generation, micro grid, grid-tied mode, coordination control operations, PV system.

I. INTRODUCTION

The ever increasing energy consumption, the soaring cost and the exhaustible nature of fossil fuel, and the worsening global environment have created increased interest in green [renewable based energy sources] power generation systems. Wind and solar power generation are two of the most promising renewable power generation technologies. The growth of wind and photovoltaic (PV) power generation systems has exceeded the most optimistic estimation. Nevertheless, because different alternative energy sources can complement each other to some extent, multisource hybrid alternative energy systems (with proper control) have great potential to provide higher quality and more reliable power to customers than a system based on a single resource.

The centralized and regulated electric utilities have always been the major source of electric power production and supply. However, the increase in demand for electric power has led to the development of distributed generation (DG) which can complement the central power by providing additional capacity to the users. These are small generating units which can be located at the consumer end or anywhere within the distribution system. DG can be beneficial to the consumers as well as the utility. Consumers are interested in DG due to the various benefits associated with it: cost saving during peak demand charges, higher power quality and increased energy efficiency. The utilities can also benefit as it generally eliminates the cost needed for laying new transmission/distribution lines.

Distributed generation employs alternate resources such as micro-turbines, solar photovoltaic systems, fuel cells and wind energy systems. This thesis lays emphasis on the fuel cell technology and its integration with the utility grid. The introduction of distributed generation to the distribution system has a significant impact on the flow of power and voltage conditions at the customers and utility equipment. Among the micro source, fuel cells are attractive due to their modular, efficient, and environmentally friendly performance. Fuel cells are capable of operating at efficiencies greater than traditional energy production methods. Moreover, the scalability of fuel cells has allowed for applications in almost every field. Fuel cell systems can be easily placed at any site in a power system for grid reinforcement, thereby deferring or eliminating the need for system upgrades and improving system integrity, reliability, and efficiency.

Therefore, proper controllers need to be designed for a fuel cell system to make its performance characteristics as desired. Development of a standalone, reduced-order, dynamic model of fuel cell power plant connected to a distribution grid via dc/ac converter. The proposed model includes the electrochemical and thermal aspects of chemical reactions inside the fuel-cell stack but the dynamics model of DC/DC and DC/AC Converters are not considered .

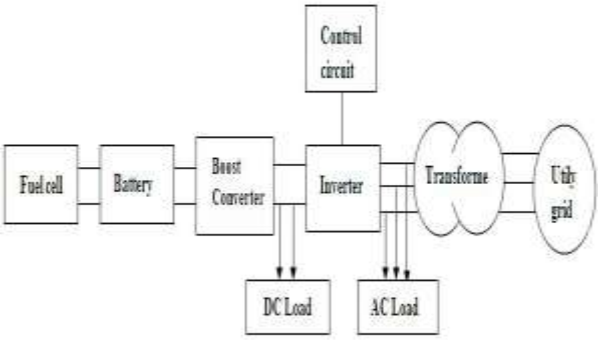


Fig.1. Modeling of Fuel Cell Connected Distribution Generation System

A novel hierarchical control architecture for a hybrid distributed generation system that consists of dynamic models of a battery bank, a solid oxide fuel cell and power electronic converters has been presented. The fuel cell power plant is interfaced with the utility grid and a three phase pulse width modulation inverter. A validated SOFC dynamic model used in this paper.

Technology	Micro turbines	Fuel cell	Wind turbine	Photovoltaic system
Output generated	25-500 KW	1KW-10MW	0.3KW-5MW	0.3KW-2KW
Installed cost ($/KW)	1,200-1,700	1,00-5,000	1,000-5000	6,000-10,000
Electrical Efficiency	20-30%	30-60%	20-40%	5-15%
Fuel Type	Natural gas, Hydrogen, Biogas	Hydrogen, Natural gas, Propane	Wind	Sunlight

1.Comparison between DGS technologies

II. FUEL CELL TECHNOLOGY

A fuel cell is an electrochemical device, which combines hydrogen fuel with oxygen to produce electric power, heat and water. In many ways, the fuel cell resembles a battery. Rather than applying a periodic recharge, a continuous supply of oxygen and hydrogen is supplied from the outside. Oxygen is drawn from the air and hydrogen is carried as fuel in a pressurized container. As alternative fuel, methanol, propane, butane and natural gas can be used. The fuel cell does not generate energy through burning; rather, it is based on an electrochemical process. There are little or no harmful emissions.

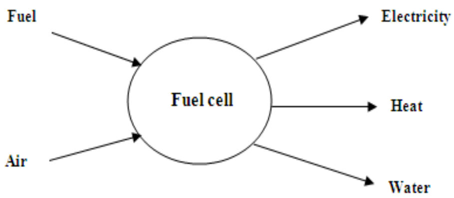


Fig.2. Single line diagram of fuel cell

Types of fuel cells:

The general classifications of fuel cells are based on the type of electrolyte used. There are many types of fuel cell

Type	Electrolyte	Fuel	Operating Temp.^{o}C
SOFC	Solid oxide electrolyte	H_2,CO,CH_4	500-200
PASC	Phosphoric acid	H_2	200
PEMFC	Solid polymer	Pure H_2	50-100
MCFC	Lithium& Potassium carbonate	H_2,CO&Other hydrocarbones	500-1000
AFC	KOH	H_2	50-200

2.Type Electrolyte, Operating Temputure & Fuel For Different Fuel cells
such as alkaline fuel cells (AFCs), phosphoric acid fuel cells (PAFCs), proton exchange membrane fuel cells (PEMFCs), molten carbonate fuel cells (MCFCs) and solid oxide fuel cells (SOFCs). Fuel cells can further be classified based on operating temperature. Details on fuel cells based on type of electrolyte, operating temperature and fuel are shown in Table

Solid Oxide fuel cells (SOFC):

Solid Oxide fuel cells (SOFC) use a hard, ceramic compound of metal (like calcium or zirconium) oxides (chemically, O_2) as electrolyte. Efficiency is about 60 percent, and operating temperatures are about 1,000 °C (about 1,800 °F). Cells output is up to 100 kW. At such high temperatures a reformer is not required to extract hydrogen from the fuel, and waste heat can be recycled to make additional electricity. However, the high temperature limits applications of SOFC units and they tend to be rather large. While solid electrolytes cannot leak, they can crack.

Among different types of fuel cells classified by the type of electrolyte material, the SOFC is considered in this paper for distributed generation performance analysis under normal operating conditions. The features of SOFC in can tolerate relatively impure fuel such as obtained from gasification of coal, operate at extremely high temperatures of 500 to 1000^o C. The reformer system of SOFC is less complex due to its using carbon monoxide as fuel along with hydrogen.

Fuel Cell Types	Phosphoric Acid Fuel Cells (PAFC)	Solid Oxide Fuel Cells (SOFC)	Molten Carbonate Fuel Cells (MCFC)	Proton Exchange Membrane Fuel Cells (PEMFC)
Size	100-200 kW	1 kW- 10 MW	0.25 – 10 MW	0.5-250 kW
Operating Temperature	180 – 200°C	800 – 1000°C	600 – 700°C	35 – 100°C
Installation Cost (/kW)	$2000-3500	$1200-4000	$800-3000	$1000-3000
Peak Power Density (mW/cm²)	~200	~200-500	~160	~700
Efficiency (Electrical)	36-42 %	45 - 60 %	45-55 %	32 – 45 %
Efficiency (with Co-generation)	Up to 80 – 85 %	Up to 80 – 85 %	Up to 80 – 85 %	Up to 80 – 85 %
Start-up Time	1-4 hrs	2-8 hrs	2-5 hrs	20 sec – 6 mins
Current Manufacturers	UTC Fuel Cells, Fuji Electric Company Ltd, Mitsubishi Electric Corp	Siemens Westinghouse Power Corp.	Fuel Cell Energy, Hitachi Ltd.	Ballard Power Systems, Avista Labs, UTC Fuel Cells, Nuvera Fuel Cells, Plug Power, H power, Ida Tech

The operating temperature of the reformer and the stacks are compatible. The SOFC system has relatively simple and response to load changes makes them suitable for large stationary power generations.

III. OPERATION OF SOFC FUEL CELL

Fuel cells are electro-chemical devices which are used to convert the chemical energy of a gaseous fuel directly into electricity. In fuel cells, a chemical reaction takes place to convert hydrogen and oxygen into water, releasing electrons in the process. In other words, that hydrogen fuel is burnt in a simple reaction to produce electric current and water. A fuel cell consists of two electrodes, known as anode and cathode that are separated by an electrolyte is shown in Fig. Oxygen is passed over the cathode and hydrogen over the anode. Hydrogen ions are formed together with electrons at the anode. Hydrogen ions migrate to the cathode through the electrolyte and electrons produced at the anode flow through an external circuit to the cathode. At the cathode, they are combining with oxygen to form water. The flow of electrons through the external circuit provides the current cell. In order to storage energy, Hydrogen and Oxygen are obtained from water by passing a direct current in a process known as electrolysis. The chemical reactions that take place inside the SOFC and directly involved in the production of electricity are as follows.

At anode

$$2H_2 + 2O^{2-} \rightarrow 2H_2O + 4e^- \text{.........}1$$

or

$$2CO + 2O^{2-} \rightarrow 2CO_2 + 4e^- \text{.........}2$$

At cathode

$$O_2 + 4e^- \rightarrow 20^- \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Overall cell reaction can be expressed as

$$H_2O + \frac{1}{2}O_2 \rightarrow H_2O$$

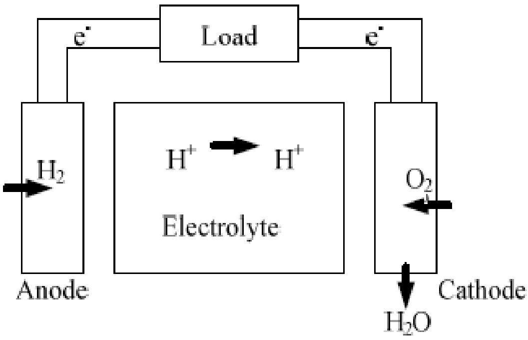


Fig.3. Schematic diagram of a fuel cell

IV. MODELLING OF FUEL CELL MODEL

A simulation is developed for SOFC in MATLAB based on the dynamic SOFC stack. Considering ohmic losses of the stack, the expression of total stack voltage can be written as

$$V_{fc} = N_0\left[E_0 + \frac{RT}{2F}\left(\ln\left(\frac{P_{H_2}}{P_{H_2O}}P_{O_2}\right)\right)\right] - rI_{fc} \ldots 4$$

Where V is the total stack voltage and r I is ohamic loss of the stack the output voltage of the stack is given by the Nernst equation . the ohmaic loss of the stack is because of the resistance of the electrodes and to the resistance of the floe of oxygen ions through the electrolyte. Partial pressure of hydrogen. Oxygen and water are given in equation below

$$P_{H_2} = \left[\frac{\frac{1}{KH_2}}{1+\tau_{H_2}S}\right](qH_2 - 2K_rI) \ldots\ldots\ldots\ldots 5$$

$$P_{O_2} = \left[\frac{\frac{1}{KO_2}}{1+\tau_{O_2}S}\right](qO_2 - 2K_rI) \ldots\ldots 6$$

$$P_{H_2} = \left[\frac{\frac{1}{KH_2}}{1+\tau_{H_2}OS}\right](2K_rI) \ldots 6$$

$$I = \left(\frac{I_{ref}}{1+\tau s}\right) \ldots\ldots\ldots 7$$

$$I_{ref} = \left(\frac{P_{ref}}{V_{fc}}\right) \ldots\ldots 8$$

fuel cell electrochemical process starts on the anode side where H_2 molecules are brought by flow plate channels. Anode catalyst divides hydrogen on protons H^+ that travel to cathode through membrane and electrons e^- that travel to cathode over external electrical circuit. At the cathode hydrogen protons H^+ and electrons e^- combine with oxygen O_2 by use of catalyst, to form water H_2O and heat. Described reactions can be expressed above equations:

Amount of chemical energy released in these reactions depends on hydrogen pressure, oxygen pressure and fuel cell temperature. Using change in Gibbs free energy, this amount can be expressed as:

$$\Delta g_g = \Delta g^o{}_f \ - RT_{fc}[\ln(PH_2) + 0.5\ln(PO_2)]\ldots\ldots9$$

where $\Delta g^0{}_f$ is change in Gibbs free energy at standard pressure, *R* universal gas constant, T_{fc} temperature and p_{O2} and P_{H2} are gas pressures. Because electrical work done by fuel cell is equivalent to released chemical energy, value of open circuit fuel cell voltage *E* meets equation:

$$E = -\left(\frac{\Delta_{gf}}{2F}\right)\ldots\ldots\ldots\ldots10$$

where *F* is Faraday's constant.

To attain actual cell voltage (on electrical couplings) v_{fc}, voltage drops caused by activation, concentration and ohmic losses have to be deducted from open circuit voltage Cathode and anode activation losses are result of breaking and forming electron-proton chemical bonds, and parasitic electrochemical reactions caused from hydrogen proton migration through membrane at zero current. Their voltage drop was calculated using formula:

$$V_{act} = V_0 + V_a(1 - e^{-C_1 i})\ldots\ldots\ldots11$$

where activation voltage drop at zero current density v_0 depends on fuel cell temperature, cathode pressure and water saturation pressure Va=f(T_{fc}, P_{ca}, P_{sat})Voltage drop v_a inserts in (5) correlation with current density *i* and depends on fuel cell temperature, oxygen pressure and water saturation pressure Va=f(T_{fc},P_{o2},P_{sat}) and c_1 is activation voltage constant.

V. DYNAMIC MODELING OF BOOST CONVERTER

The main objective of the boost converter is to track the maximum power point of the PV array by regulating the solar panel terminal voltage using the power voltage characteristic curve.

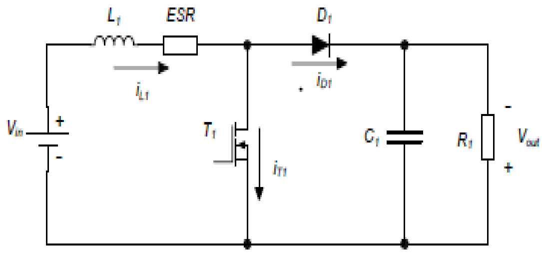


Fig.4. Boost Converter

$$Vin - L\frac{di_1}{dt -}(1-D)V_C - ESRi_1 = 0\ldots12$$

$$i_{D1} = i_{C1} + i_{L1}\ldots\ldots13$$

$$\begin{bmatrix} \dot{i}_{L_1} \\ \dot{v}_{C_1} \end{bmatrix} = \begin{bmatrix} \frac{-ESR}{L_1} & \frac{-(1-D)}{L_1} \\ \frac{1-D}{C_1} & \frac{-1}{R_1 C_1} \end{bmatrix} \begin{bmatrix} i_{L_1} \\ v_{C_1} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_1} \\ 0 \end{bmatrix} [V_{in}]\ldots14$$

$$[V_{Out}] = [0 \quad 1]\begin{bmatrix} i_{L_1} \\ v_{C_1} \end{bmatrix} + [0][V_{in}]$$

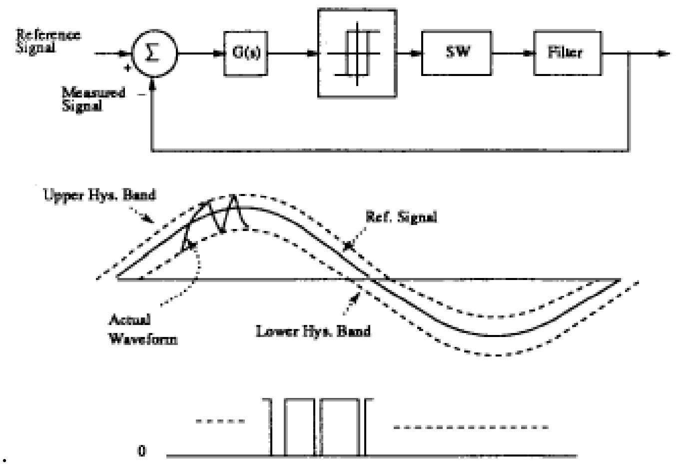
VI. MODELING OF BATTERY

Battery acts as a constant voltage load line on the PV array and is charged both by PV array and induction generator .the battery is modeled as a nonlinear voltage source whose output voltage depends not only[8-9] on the current but also on the battery state of charge(SOC), which is non linear function of the current and time :

$$V_b = V_O + R_b i_b - K\frac{Q}{Q + \int i_b dt} + A\exp(i_b dt)\ldots.16$$

VII. PROPOSED HYSTERESIS CONTROL FOR DISTRIBUTION GENERATION MODE

Hysteresis band PWM is basically an instantaneous feedback current control method of PWM where the actual current continuously tracks the command current within a hysteresis band. The control circuit generates the sine reference current wave of desired magnitude and frequency. It is compared with the actual phase current wave. When the current exceeds a prescribed hysteresis band, appropriate switches are turned on so that actual current is with in the hysteresis band. Hysteretic control operation



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VIII. SIMULATION RESULTS

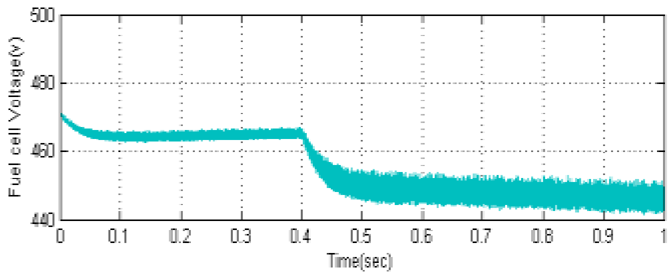

Fig.5. Fuel cell DC output voltage

The fig shows the Fuel cell DC output voltage which is increase correspondingly with the chemical reaction initially output voltage constant from 0.1 to 0.4 after 0.4 the voltage will be decrease means the chemical reaction changes .when output voltage is taken as feed back to fuel system to main constant output voltage.

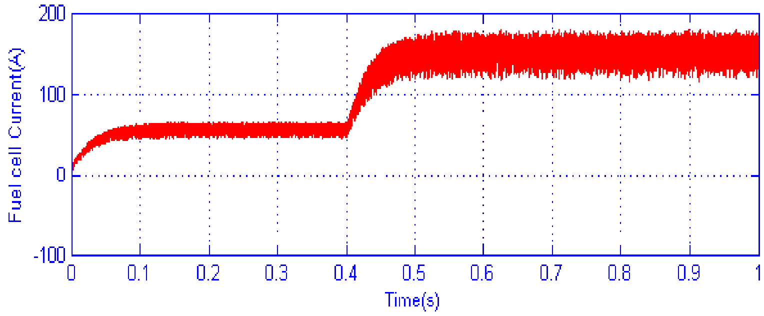

Fig.6. Fuel cell DC output current

The fig shows the Fuel cell DC output current which is increase correspondingly with the chemical reaction and voltage initially output voltage constant from 0.1 to 0.4 after 0.4 the voltage will be decrease means the chemical reaction changes.

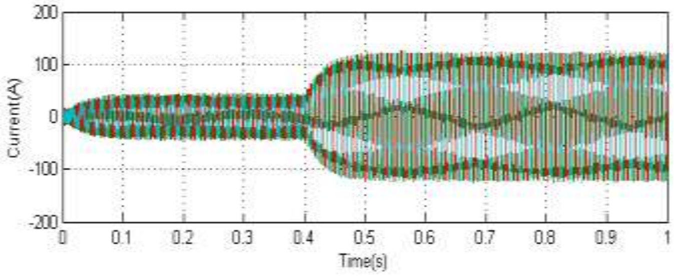

Fig.7. Fuel cell current at inverter

The fig shows current at inverter. with is taken from when chemical reaction is done the battery charge and that can be transfer to converter it will convert DC to AC .the output of inverter three phase currents.

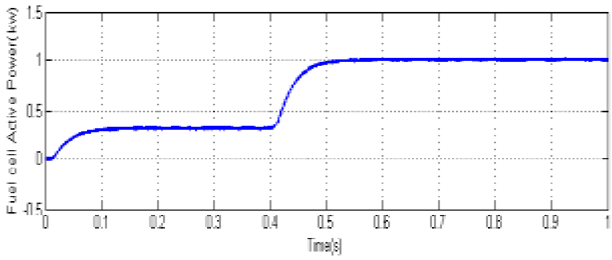

Fig.8. Fuel cell active power

The fig shows fuel cell active power in "kw" which is varies linearly with the chemical reaction means corresponding output voltage and current.

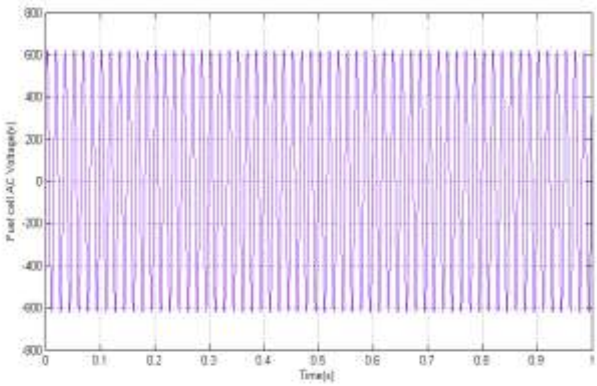

Fig.9. three phase voltage at grid

The fig shows the voltage at grid. This voltage matches with the actual voltage of grid through chemical reaction, inverter and step up transformer.

IX. CONCLUSION

This paper simply provides the alternative energy solution for different consumer applications and industrial applications. the design and developed fuel system configuration is done in MATLAB/SIMULINK environment. Modeling and simulation study of a SOFC power system is investigated in this paper. A validated SOFC dynamic model is used to model the fuel cell system. A three phase inverter has been modeled and connected between the SOFC power system on one side and the utility grid on the other side through an ideal transformer. A control strategy for the inverter switching signals has been discussed. future work this paper modeling of modeling micro turbine and it is connecting to fuel cell and maintain stable operation between load source under various load and source changing conductions by using proper controllers.

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