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Compact Hybrid Power Source Using Fuel Cell and PV Array

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***Abstract*-** Different energy sources and converters need to be integrated to meet sustained load demands while accommodating various natural conditions. A hybrid system of a fuel cell, PV array and battery connected to a load is presented in this paper. This paper focuses on the integration of photovoltaic (PV) and fuel cell (FC) for sustained power generation. Fuel Cell and PV are the primary power sources of the system, and a battery combination is used as a backup and a long-term storage system. An overall power management strategy is designed for the proposed system to manage power flows among the different energy sources and the storage unit in the system. A simulation model for the hybrid power source has been developed using MATLAB/Simulink.

***Index Terms*-** Fuel Cell, PV Array, Inverter, Hybrid energy storage system, Battery, Boost Regulator, Output Voltage .

I. Introduction

Solar energy is the most readily available source of energy. It is free. It is also the most important of the non-conventional This feature of directness of conversion has been largely responsible for making photovoltaic such a popular mode of generation of electricity sources of energy because it is non-polluting. Energy from the sun is the best option for electricity generation as it is available everywhere and is free to harness. On an average the sunshine hour in India is about 6hrs annually also the sun shine shines in India for about 9 months in a year. Electricity from the sun can be generated through the solar photovoltaic modules (SPV). Fuel cells have emerged as one of the most promising technologies for meeting new energy demands. They are environmentally clean, quiet in operation, and highly efficient for generating

Electricity .A fuel cell is an electrochemical energy conversion device. A fuel cell converts the chemicals hydrogen and oxygen into water, and in the process it produces electricity.The source of hydrogen is generally referred to as fuel and this gives the fuel cell its name, although there is no combustion involved. Oxidation of hydrogen instead takes place electrochemically in a very efficient way. During oxidation , hydrogen atoms react with oxygen atoms to form water; in the process electrons are released and flow through an external circuit as an electric current. The fuel cell in this hybrid power source is PEMFC (Prototype Exchange Membrane Fuel Cell).Generally hydrogen is used as fuel. It operates at relatively low temperature(100 c). The electrolyte of a PEM fuel cell consists of a layer of solid polymer, which allows protons to be transmitted from one side to the other.

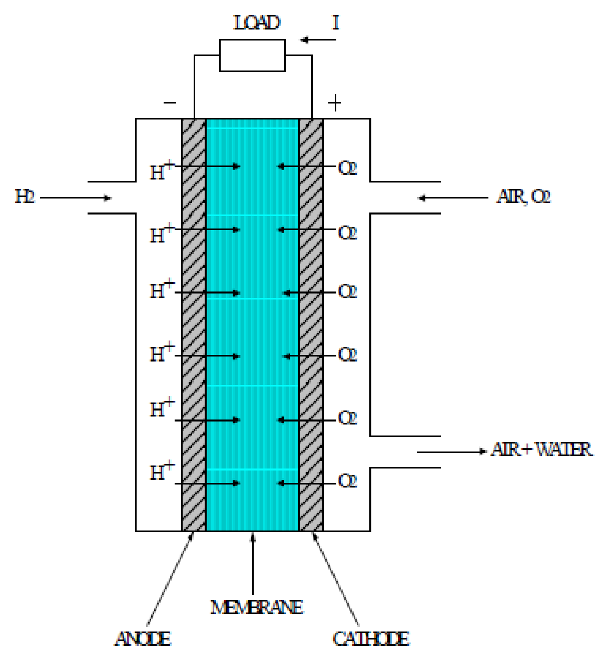

Fig .1. Schematic Diagram of typical PEM Fuel

As mentioned earlier the Hybrid power Source is an integration of Fuel Cell, PV Array and battery. The Average power generated from the energy sources is fed to boost Regulator. The boost Regulator Steps up the voltage to the desired level. Once the required voltage is received from the boost regulator , it is in turn fed to inverter . The inverter converts the DC to AC voltage, as the output from Fuel Cell and PV array is DC.

II. HYBRID POWER SOURCE

The Hybrid power source as proposed in this paper consists on Fuel Cell, PV array an d Battery. The system can work in three different modes:

Mode I: Fuel Cell and Battery
Mode II:PV Array and Battery
Mode III: Fuel Cell, PV Array and Battery

When the Fuel cell runs out of Fuel then the energy from the PV array can be used and vice versa. When the load demand increases, both the energy sources in combination with the battery can be used. In this system battery is mainly used to store

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the excess energy generated by PV array during the day. This energy stored in order to meet the high load demands. The block diagram below shows the Hybrid power source, Boost regulator and Inverter.

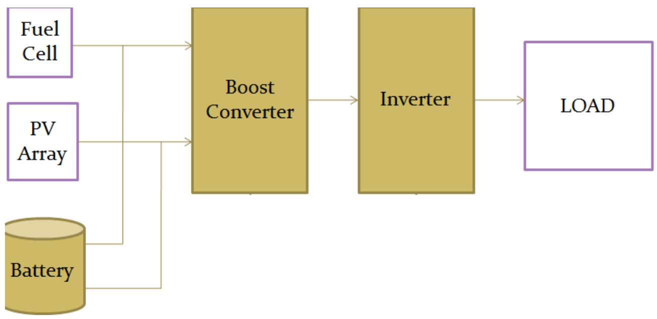

Fig. 2. Block diagram of Compact Hybrid Power Source

PEMFC Model: The PEMFC is mainly modeled using the Nerst Equation . The output voltage of a single cell can be defined as the result of the following expression [1].

Vfc= Enerst -Vact -Vohm - Vconc [1]

Where Vfc represents the Fuel Cell voltage (V), Enerst represents the Nerst voltage (V), Vact represents Actual voltage (V), Vohm represents Ohmic voltage drop (V) and Vconc represents Concentration Voltage (V).The reversible voltage of the cell, Enerst is calculated from a modified version of the equation [2].

Enerst=

$$1.229-0.85*10^{-3}(T-298.15)+4.31*10^{-5}*T\,[\ln(PH_2)+\tfrac{1}{2}\ln(PO_2)]$$ [2].

Where T represents the Temperature (K), PH2 represents the partial pressure of the Hydrogen (N/m2) and PO2 represents the partial pressure of the oxygen (N/m2).The following table shows the circuit parameters.

TABLE-I
MATHEMATICAL CIRCUIT PARAMETERS

Parameters	Values
Temperature(T[K])	323
Concentration resistance ($R_c[\Omega]$)	0.0003
Membrane resistance ($R_m[\Omega]$)	$6.29*10^{-6}$
Current density ($J[A/m^2]$)	500
Maximum current density ($J_{max}[A/m^2]$)	1500
Parametric co-efficient (B[V])	0.016
Number of cells (N)	55

PV Array Model:

A photovoltaic system converts sunlight into electricity.

The basic device of a photovoltaic system is the photovoltaic cell. Cells may be grouped to form panels or modules. Panels can be grouped to form large photovoltaic arrays.

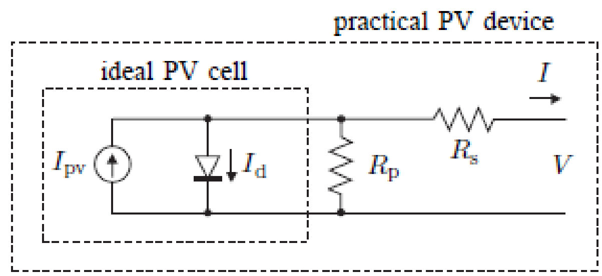

Fig.3. Single Diode Model Of the theoretical photovoltaic cell and equivalent circuit of practical photovoltaic device including series and parallel resistances.

The basic equation for designing a photovoltaic cell is shown below:

$$I = I_{pv} - I_0 \left[\exp\left(\frac{V + R_s I}{V_t a}\right) - 1\right] - \frac{V + R_s I}{R_p}$$ [3]

where Ipv and I0 are the photovoltaic and saturation currents of the array and Vt = NskT/q is the thermal voltage of the array with Ns cells connected in series. Cells connected in parallel increase the current and cells connected in series provide greater output voltages.

III. MATLAB/SIMULINK MODEL

A complete system model composed of a hybrid energy source which is composed of Fuel Cell, PV Array and battery, Boost regulator , Inverter and load. PEMFC model, PV cell connected to a Ni-Metal Hydride battery model has been developed and simulated using MATLAB/Simulink program. This software offers the advantage allowing the user to view the system at different levels, such that the models are easily connected together. The parameters can be changed during simulation, and the results from different simulations are eventually analyzed.

TABLE-II
SIMULINK MODEL PARAMETERS

PEMFC	
Maximum power(kW)	**5000**
Number of cells	**55**
NI-METAL HYDRIDE BATTERY	
Nominal voltage(V)	**1.2**
Initial SOC(%)	**50**
Rated capacity (Ah)	**1.5**

TABLE II represents the values of the parameters used in modelling of Proton Exchange Membrane Fuel Cell and Ni-Metal Hydride Battery.TABLE III which is shown below represents the values of the parameters used in designing photovoltaic array.Based on thevalues of these circuit parameters , the simulation results are changed. Any changes in the simulation results can be achieved by changing the values of these parameters.

TABLE-III

PV MODEL PARAMETERS	
G	600
Kv	15
Vocn(V)	70
Ipvn(A)	120
a	30
k	78
Ns	6
q	3
Gn	8.5
Ki	8
Iscn	17
Tn	200
Rs	1

The figure below shows the the full system MATLAB\SIMULINK model. The subsystems for the fuel cell and PV array is designed based on their respective design equations. Separate subsystems are created and incorporated into the main simulation . Also, the above circuit parameter values are used. In the case of PV Array the parameters are assigned in MATLAB program file. The rest are used for fuel cell and battery.

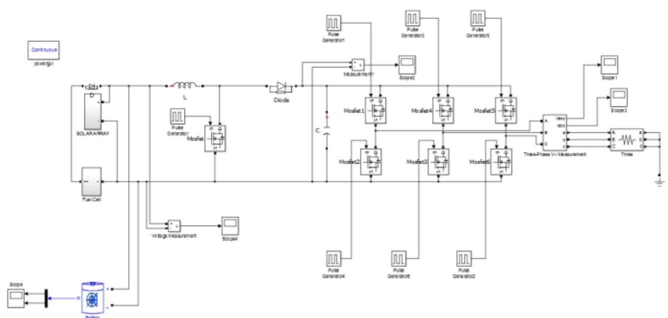

Fig.4. MATLAB/SIMULINK model of the full system.

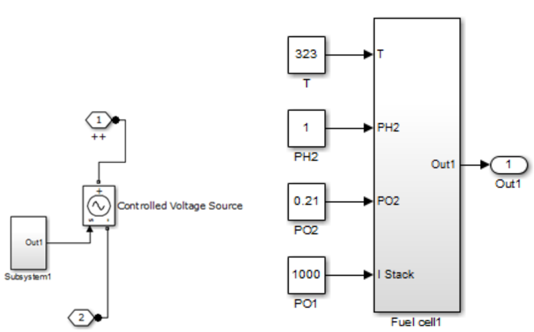

Fig.5. Subsystem of the PEMFC

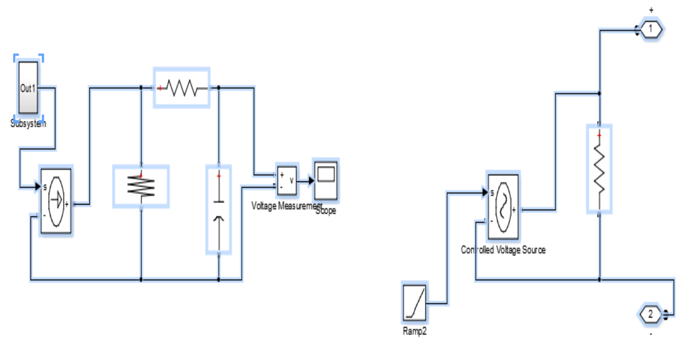

Fig.6. Subsystem for PV Array

IV. SIMULATION RESULTS

An average of 44v system has been simulated and results and shown in the following figures.the simulation results for three different modes is analyzed and corresponding results are tabulated below .

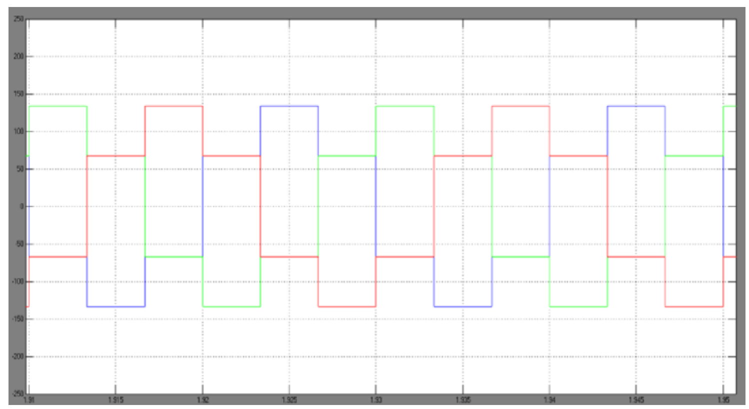

Fig.7. Output Voltage with load for Mode I

In the Mode I the only energy source is fuel cell. Battery is used to store the excess energy generated. It is observed that the voltage from fuel cell is 27V. This voltage is then fed to the boost regulator which steps the voltage to 210V. this voltage is converted to AC by inverter and a 100kohm load is connected to the inverter terminals. The output measured across the Inverter terminals with load is 135V.

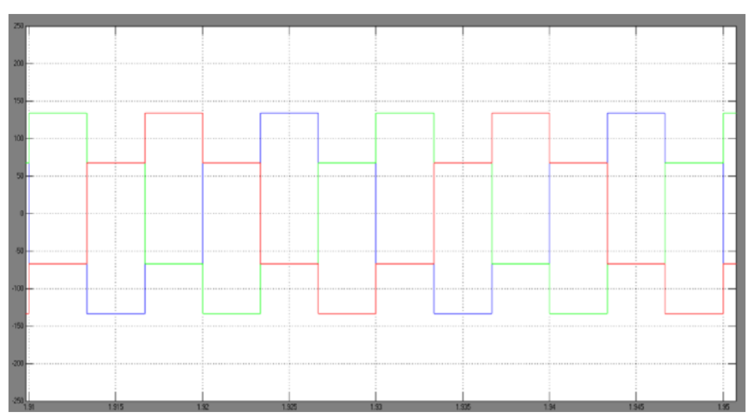

Fig.8. Output Voltage with load for Mode II

In Mode II the only energy source is PV Array .As usual the battery stays connected to the system in order to store the excess energy generated which can be used during high load demands.the voltage generated from PV Array is 39.4V. This in turn is fed to the boost regulator to step up. The stepped up voltage which is around 245V is given to the inverter. With a 100kohm load being connected to the inverter terminals, the output measured is 175V.

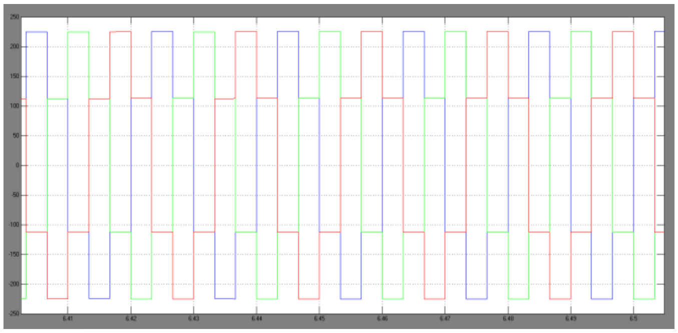

Fig.9. Output Voltage load for Mode III

In Mode III the both the energy sources are used.As usual the battery stays connected to the system in order to store the excess energy generated which can be used during high load demands.the voltage generated from PV Array is 44V. This in turn is fed to the boost regulator to step up. The stepped up voltage which is around 3155V is given to the inverter. With a 100kohm load being connected to the inverter terminals, the output measured is 230V.

V. POTENTIAL APPLICATIONS AND ADVANTAGES

Hybrid renewable energy systems (HRES) are becoming popular for remote area power generation applications due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. A hybrid energy system usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply. Hybrid system can guarantee the certainty of meeting load demands at all times at reasonable cost.

VI. CONCLUSION

A compact Hybrid power source has been simulated and the experimental results show us that this power source is reliable at all times. The use of solar & FC hybrid power generation is an especially vivid and relevant choice for as these are power sources of technological, political, and economic importance in their state. Modelling and analysis of the system have been explained and simulation and experimental results are presented. A hybrid PEMFC, PV Array and battery model system is developed and simulated using the MATLAB/Simulink software. Simulation results show that using the hybrid system different load demands can be met.Also, by varying the design values of the models, output voltage is achieved at desired levels. A battery storage system solves these problems by charging or discharging, depending on the load demand. The battery is discharged to supply the extra load requirement while the PEMFC model and PV Array supplies the maximum power.

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