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Integrated Renewable Energy system with Hydrogen energy Storage

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ABSTRACT— *The system integrates various renewable energy sources and converts it into stable power for standalone operation. The Renewable energy is then converted into Hydrogen using fuel cells to store the renewable energies in an electrochemical form. The stored Hydrogen is used to generate clean electricity by fuel cells to meet energy demand at a desired time. Renewable Energies from Solar Photovoltaic, Wind are integrated with combined Electrolysis system. Electricity from the above sources can be used to run an electrolyzer. The electrolyzer splits water into hydrogen and oxygen. The hydrogen and oxygen can be used to power a fuel cell and produce electricity. Sometimes there are low wind speeds and lesser sunny conditions and therefore power generation by solar and wind energy is reduced. The proposed system in which solar and wind energy is integrated with fuel cell to provide a continuous power supply to a small local load to enhance Reliability of power supply and stores the excess energy in to hydrogen and oxygen. Here PV and wind energy is used as the primary source of power with the fuel cell section acting as a power backup system. Renewable energy portability and long term storage of renewable energies are achieved in the proposed system.*

Keywords—Renewable energy, Fuel cells, Solar, Wind, Electrolyzer.

1, INTRODUCTION

Power generation and storage is one of the major areas of research in the renewable energy world. Increase in energy demand and decrease in fossil fuels leads to produce the power by means of renewable energies. The awareness in environmental pollution results to find alternate ways to produce energy with low green house gas emissions. Fuel cell plays a vital role in distributed energy generation and storage with minimal emissions. The experimental system proves that the power generation by renewable sources and stored it an efficient manner. The fuel cell demonstrated in this system was reversible proton exchange membrane fuel cell, it operates in electrolyzer mode and also power generation mode. The external current applied to the Fuel cell works as an electrolyzer and produces hydrogen and oxygen from water. When the load applied to the device then the device turns in to power generation mode and produce electricity by utilizing hydrogen and oxygen. A miniature model was proposed in this system to prove that the renewable energies are stored in efficient manner.

2, WIND POWER GENERATION SYSTEM

The power extracted from wind turbine is calculated by the equation

$$P_{wind} = \frac{1}{2} C_p \, \rho \, A \, V^3 \quad (1)$$

P_{wind}=Power Extracted from wind turbine, C_p=power co-efficient, ρ= Air density in K_g /m^3
A=swept area of rotor in m^2, V=wind speed in m/s
The Torque is given by the ratio between the turbine power and rotor speed

$$T_{wind}=P_{wind}/W_{wind} \quad (2)$$

T_{wind}=Torque produced by wind turbine(N-m), W_{wind}=Rotor speed of turbine in rad/sec
Here the turbine is directly connected to the generator without and transmission gears and it is assumed to be negligible losses. The torque supplied to the generator is equal to torque produced by wind turbine. According to Betz's limit the power extracted from wind is less than or equal to 59.3%.The multi-pole permanent magnet synchronous generator (PMSG) is more efficient for small scale wind turbines because of its robust construction, low maintenance requirements and minimal losses. For small scale wind turbines, the efficiency of the system is higher when compared to other generators. Due to the absence of damper winding and field winding in Multi-pole synchronous generators rotor core, the transient currents are induced, when the load changes the field winding would not contribute to damping.

In permanent magnet synchronous generators, the transient and sub transient reactances are negligible.

Xd= Xd' = Xd''

Xq= Xq' = Xq''

XdandXq -synchronous reactance

Xd' and Xq' -transient reactance

Xd" and Xq" -sub-transient reactance

3, SOLAR POWER GENERATION SYSTEM

The modeling of photovoltaic (PV) panel is based on one diode equivalent circuit as shown in figure 1.

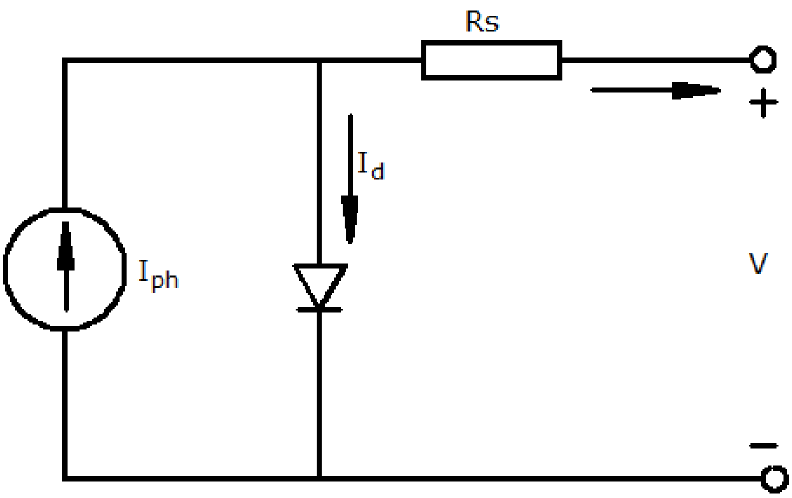

Fig 1: Single solar cell model

The current and voltage relationship of the equivalent circuit can be calculated buy equating the photovoltaic current I_{ph} and diode current I_d. The output current I as follows:

$$I = I_{ph} - I_d = I_{ph} - I_{sat}\,[e^{\frac{q(V+IRs)}{nkT}} - 1] \quad (3)$$

Where

Iph = light current [A],*Isat* = diode reverse saturation current [A],*Rs*= series resistance [Ω]

V =operating voltage [V],I =operation current [A],q = charge of one electron ($1.602X10^{-19}$C) n = Diode ideality factor,k = Boltzman's constant ($1.38 X 10^{-23}$J/K),T = Junction temperature [K],The previous equations have been modeled into the MATLAB Simulink environment

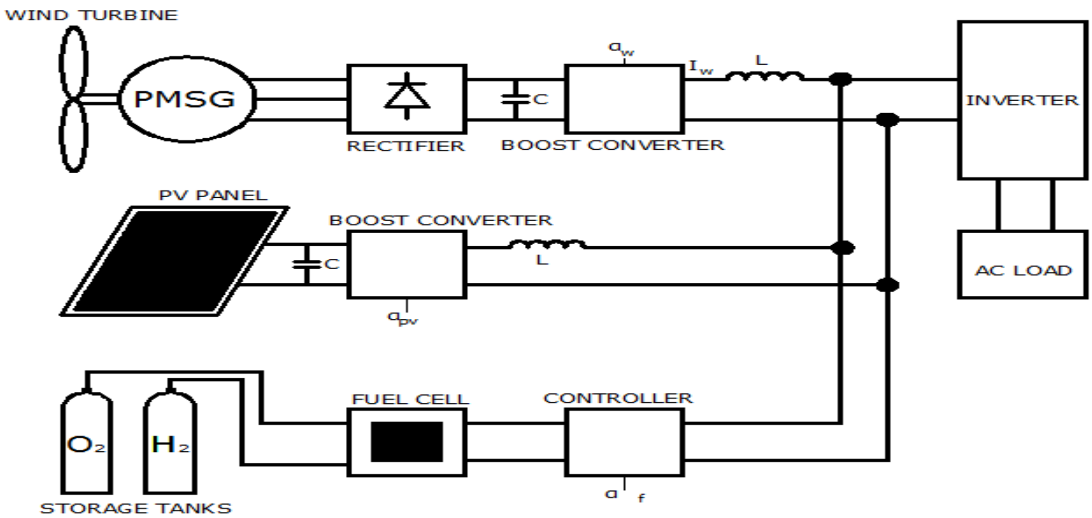

Fig 2: Block diagram of Hybrid power system with Fuel cell energy Backup and Generation

4, MODELLING OF ELECTROLYZER SYSTEM

An Electrolyzer is an electrochemical device that uses electrical current to splits water into hydrogen and oxygen. In a proton exchange membrane fuel cells, the membrane layer decompose the water in to hydrogen and oxygen proportional to the electric current applied on it. According to faraday's law the hydrogen production rate is directly proportional to transfer rate of electrons at electrodes.

$$\eta_{H2}=\eta_F . n_n . i_e/2F \quad (4)$$

Where

η_{H2}=Hydrogen production rate, mol/s, η_F= Faraday's efficiency,n_n = No. of electrolyzer cells in series, i_e = electrolyzer current [A], F = Faraday constant [C kmol−1].

The ratio between the actual amount and the theoretical amount of hydrogen produced in the electrolyzer is known as Faraday efficiency. Assuming that the working temperature of the electrolyzer is 40 °C, Faraday efficiency is expressed by:

$$\eta F = 96.5 \, X \, [e^{\frac{0.09}{i_e} - 75.5/i_e^2}] \quad (5)$$

Based on the above equations, a simple electrolyzer model is modeled using Simulink, which is shown in Fig: 3

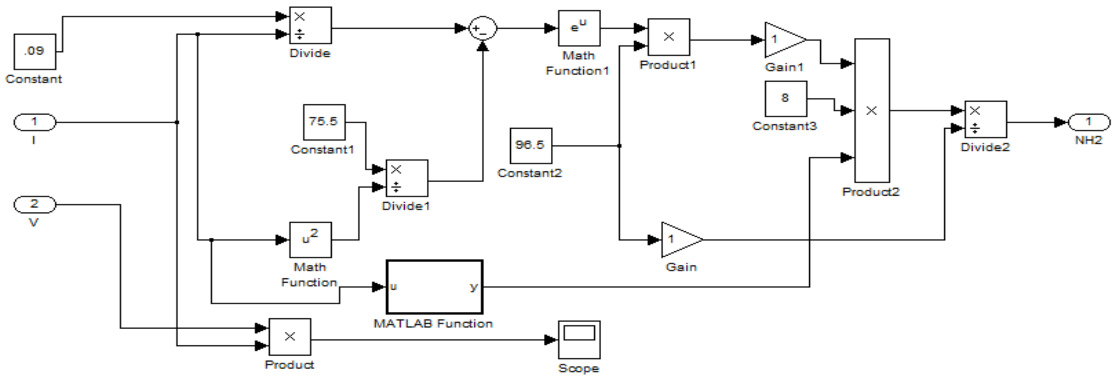

Fig 3: Simulink model of Electrolyzer

4, MODELLING OF HYDROGEN STORAGE SYSTEM

The generated hydrogen from electrolyzer is stored in tanks and the hydrogen is stored in tanks by compressed hydrogen or liquid hydrogen. The dynamics of hydrogen stored in tanks can be calculated with the help of tank pressure.

$$P_b - P_{bi} = Z\,.[N_{H2} R T_b / M_{H2} V_b] \quad (6)$$

P_b = Pressure of tank (pascal), P_{bi}= Initial pressure of the storage tank (pascal),

R = Universal (rydberg) gas constant (J/kmol K)

T_b = Operating temperature (K), V_b = Volume of the tank (m^3), Z = Compressibility factor as a function of the pressure, $Z=PV_m/RT$, P=Pressure, V_m= Molar volume, T=Temperature.

Here the Tank pressure is calculated directly by calculating the ratio of hydrogen flowing to the tank, the auxiliary power requirements such as pumps, valves, fan and compressors

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are ignored in the model. The simulink model is shown in figure: 4

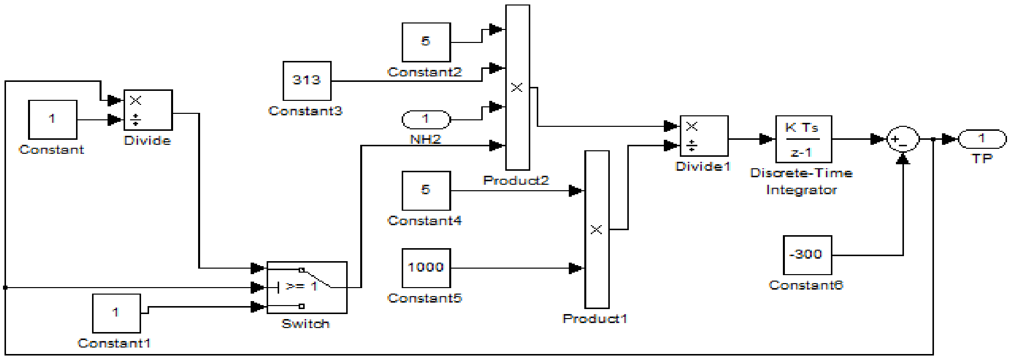

Fig 4: Simulink model of H_2 storage tank

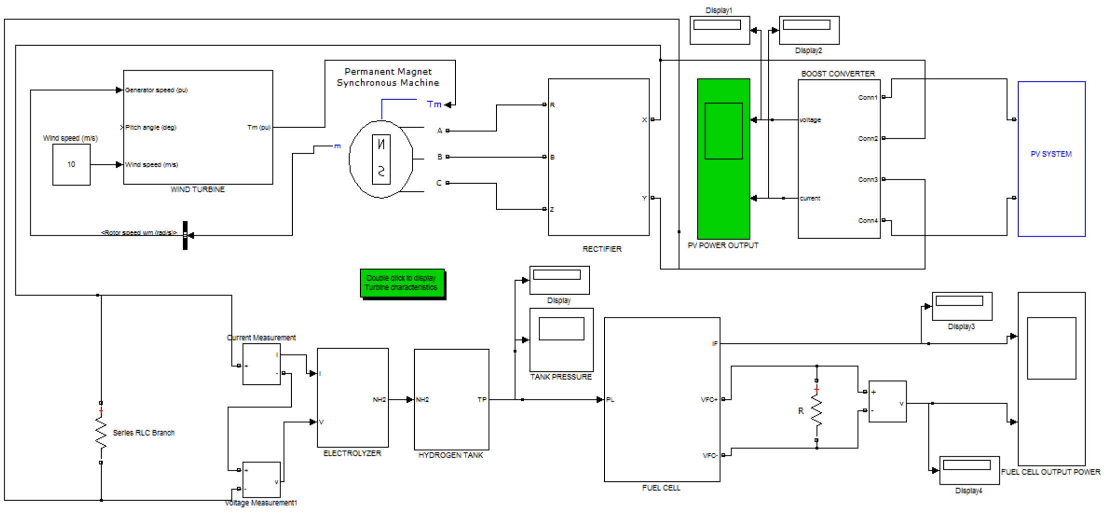

Fig 5: Simulink model of overall system

5, RESULTS AND DISCUSSION

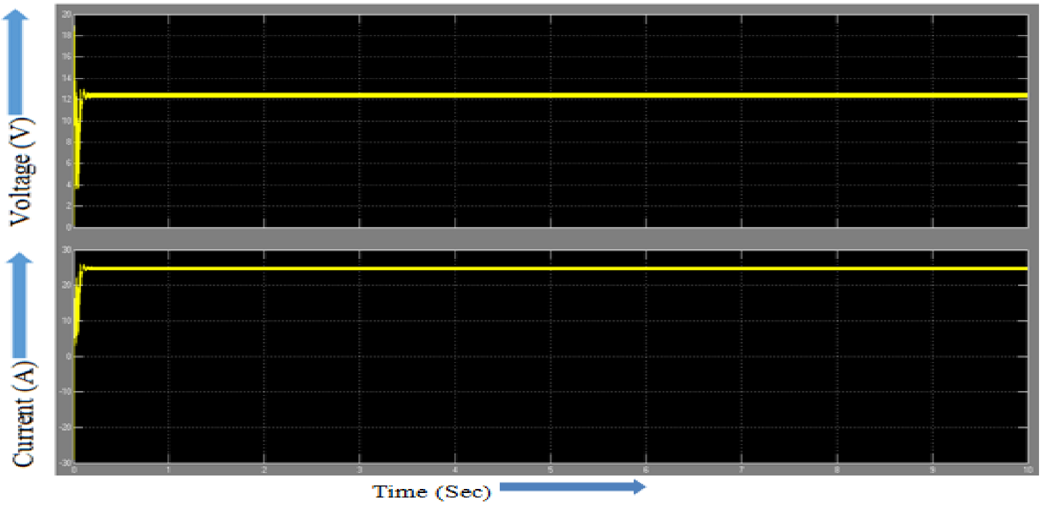

Fig 6: DC Voltage (V) and Current (I) obtained from PV and wind system at short circuit condition Voltage=12V, Current=25A

The renewable energy systems are integrated and can able to deliver 300watts of power for standalone operation as shown in fig 5.The solar irradiance is fixed at 1000W/m^2, and wind speed of 10m/s, when the load is not connected or the power utilization is less than the generated power then the excess power is diverted to electrolyzer and stores the available energy in the form of hydrogen and oxygen. The stored hydrogen is used to generate power during load demand using fuel cell. The stored hydrogen is used for clean power generation and Hybrid Electric Vehicles (HEV).

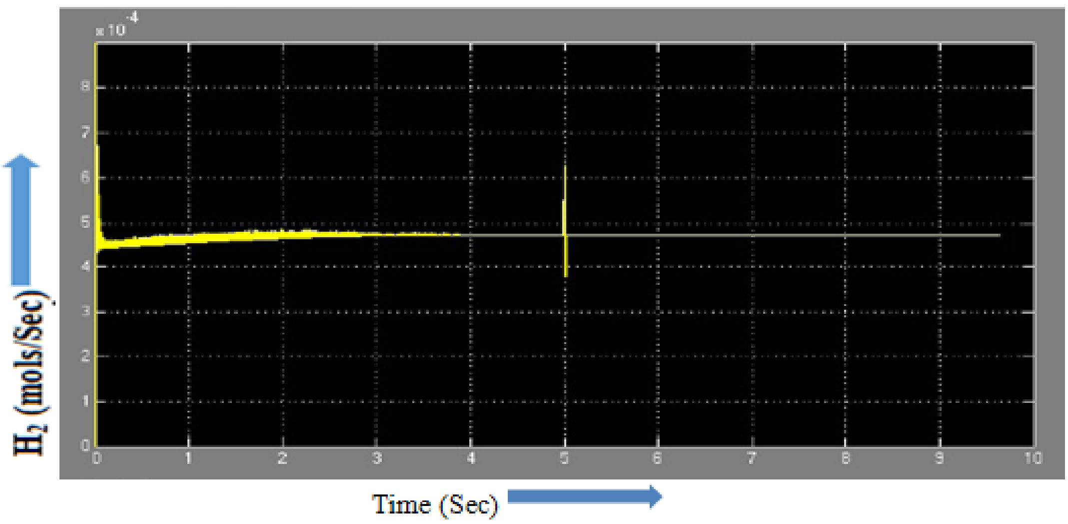

Fig 7: Hydrogen generated in Electrolyzer with respect to load current,

H_2= 4.97x10^{-4} mols/sec

At standard atmospheric condition the density of H_2 is 0.0899 kg/m3, the normal liter contains 0.0899 grams of hydrogen. The higher calorific value of hydrogen is 141.790 MJ/kg and the lower calorific value is 121 MJ/kg at STP.STP – Standard Temperature and Pressure – is defined as air at 0^oC(273.15 K, 32^oF) and 1 at (101.325 kN/m^2, 101.325 kPa, 14.7 psia, 0 psig, 30 in Hg, 760 torr). Generally 1 KJ is equal to 0.27 WH of energy. If 1 liter of Hydrogen is stored in a cylinder will provide approximately 3 Watt-hour of energy [3]. Hydrogen generated in Electrolyzer with respect to load current is shown in figure 7; it is evident that the tank pressure increased from 0 psi to 300 psi in fig 8.

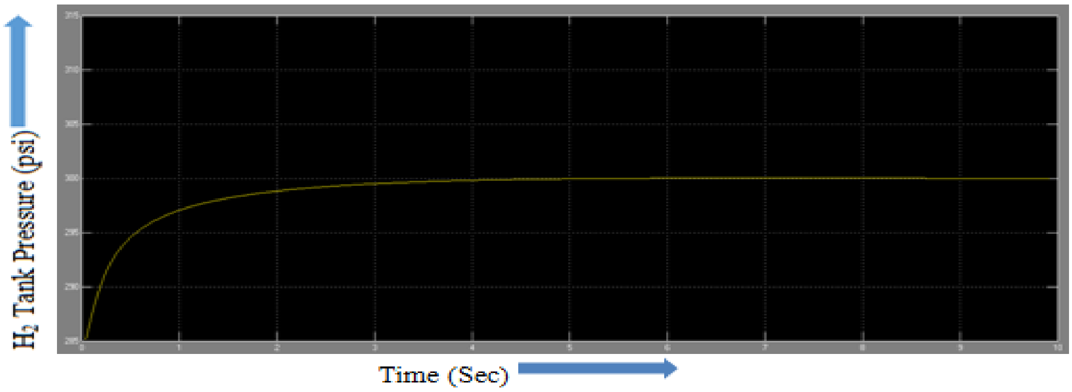

Fig 8: Hydrogen Storage Tank Pressure, Tank Pressure (Tp) = 300 psi

6, CONCULSION

In this paper, the solar and wind energy systems are modeled with hydrogen energy storage system in MATLAB Simulink environment. Renewable energy systems are seasonal and are not stable. The off-peak availability of renewable energies should be effectively stored and utilized during peak load demand. The storage system explained in this paper provides excellent performance during uneven power generation by renewable energy sources. The electrochemical energy storage system increased energy portability, reliability of energy storage and can able to store it for long period of time. The conceptual design of hydrogen energy storage system integrated with renewable energy systems is explained. The hydrogen energy power generating system holds the potential for zero emission and safe as gasoline, and it removes the fossil fuel dependency. In future electrochemical energy storage systems provide green and clean energy storage and act as a alternate fuel for hybrid electric vehicles and power generation systems.

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8,BIOGRAPHY

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