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International Journal of Innovative Research in Technology, Science & Engineering (IJIRTSE)
ISSN: 2395-5619, Volume – 2, Issue – 6. June 2016

“Grid-Connected and Stand-alone Hybrid Solar PV-Wind-Fuel Cell System”

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Abstract* — Renewable and hybrid energy systems (HESs) are expanding due to environmental concerns of climate change, air pollution and depleting fossil fuels. Photovoltaic (PV) and wind energy sources are the most widely adopted. However, the biggest challenge is the need for energy storage systems (short term storage for compensation of day/night cycles as well as long term storage for smoothing the seasonal energy harvest distinction), owing to the fact that energy from solar and wind is intermittent in nature. As the wind turbine output power varies with the wind speed and the solar cell output power varies with both the ambient temperature and radiation, a Fuel Cell (FC) system can be integrated to store excess wind and solar energies under all conditions. The combination of hydrogen storage using FC may be a solution for long term storage of solar PV and wind power. This proposed hybrid power system can tolerate the rapid changes in natural conditions and suppress the effects of fluctuations on the voltage within the acceptable range. This gives option for both off-grid and on-grid-connected system as per the user demand. FC can be effectively used for load leveling when the generation exceeds the demand, excess generated energy can be converted and stored as hydrogen by electrolysis of water. During peak load time, when the demand exceeds the generation, the stored hydrogen would be used in FC to meet additional demand. The hydrogen stored can also be used in Hydrogen fuel cell vehicles (FCVs). By replacing the internal combustion engine in automobiles with the hydrogen fuel cell, we could achieve zero emissions of pollutants into the environment. The transformation of the existing transportation system is a key to solving many of the world’s environmental problems and significantly improving the quality of the air that we breathe. Use of hydrogen as transportation fuel could reduce dependency on imported oil. Throughout the paper, current and future perspectives regarding sustainable development applications of hydrogen and electricity production in the present energy scenario are considered.

Keywords* — Renewable energy resources, Need for energy storage systems, Electrolyzer, Fuel cell, Off-Grid and Grid Interconnection, Residential Fueling System.

I. INTRODUCTION

The conventional fossil fuel energy sources such as petroleum, natural gas, and coal which meet most of the world’s energy demand today are being depleted rapidly. Also, their combustion products are causing global problems such as the greenhouse effect and pollution which are posing great danger for our environment and even for the entire life on our planet. Photovoltaic generators which directly convert solar radiation into electricity have a lot of significant advantages such as being inexhaustible and pollution free, silent, with no rotating parts, and with size-independent electric conversion efficiency. Due to harmless environmental effect of PV generators, they are replacing electricity generated by other polluting ways. But, a PV power generation experiences large variations in its output power due to intermittent weather conditions. In many regions of the world, the fluctuating nature of solar radiation means that purely PV power generators for off-grid applications must be large and thus expensive. One method to overcome this problem is to integrate the photovoltaic plant with other power sources such as diesel, fuel cell (FC), or battery back-up. The fuel cell beak-up power supply is a very attractive option to be used with an intermittent power generation source like PV power because the fuel cell power system is characterized with many attractive features such as efficiency, fast load-response, modular production and fuel flexibility. Its feasibility in co-ordination with a PV system has been successfully realized for both grid-connected and stand-alone power applications. Due to the fast responding capability of the fuel cell power system, a photovoltaic-fuel cell (PVFC) hybrid system may be able to solve the photovoltaic’s inherent problem of intermittent power generation. Unlike a storage battery, which also represents an attractive back-up option, such as fast response, modular construction and flexibility, the fuel cell power can produce electricity for unlimited time to support the PV power generator. Therefore, a continuous supply of high quality power generated from the PVFC hybrid system is possible day and night. Environmental impacts of the fuel cell power generation are relatively small in contrast to other fossil fuel power sources.

Therefore, the fuel cell power system has a great potential for being co-ordinate with the PV generator to smooth out the photovoltaic power's fluctuations.

II. HYDROGEN

A. Hydrogen production by Electrolysis of Water:

Electrolysers generate hydrogen by splitting the water molecule H_2O into its constituent elements Hydrogen and Oxygen in a process which is the reverse of the electrochemical action which takes place in a fuel cell. An electric current is passed through the water between two electrodes. Hydrogen is formed at the cathode connected to the negative supply voltage terminal and Oxygen is formed at the anode connected to the positive supply voltage terminal.

Anode (positive): $2H_2O \rightarrow O_2+4H^++4e^-$ (1)

Cathode (negative): $4H^++4e^- \rightarrow 2H_2$ (2)

OVERALL: $2H_2O \rightarrow O_2+2H_2$ (3)

B. Hydrogen Storage:

Hydrogen is the lightest chemical element and offers the best energy to weight ratio of any fuel. The major drawback to using hydrogen is that it has the lowest storage density of all fuels. However, it is possible to store large quantities of hydrogen in its pure form by compressing it to very high pressure and storing it in containers which are designed and certified to withstand the pressures involved. The various forms of hydrogen storage are

1) Storage in Liquid Form
2) Storage in Gaseous Form
3) Storage in Hydride Form

III. FUEL CELL

A fuel cell is a device that converts directly the chemical energy stored in gaseous molecules of fuel and oxidant into electrical energy. When the fuel is hydrogen the only by-products are pure water and heat. The overall process is the reverse of water electrolysis. In electrolysis, an electric current applied to water produces hydrogen and oxygen; by reversing the process, hydrogen and oxygen are combined to produce electricity and water (and heat).

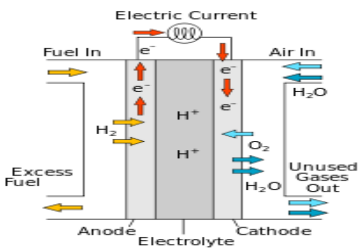

Fig.1. Fuel cell working

At the anode: $H_2 \rightarrow H^+ + 2e^-$ (4)

At the cathode: $\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$ (5)

Overall combustion reaction: $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ (6)

IV. STAND – ALONE SYSTEM

A. DC Coupled System Topology:

In this topology, all generator and storage units are tied to the DC bus-bar. The output of all AC power sources, if available, is converted into DC, then added to the output of all DC power sources to a main DC bus-bar, which is connected to the AC user load through a main DC/AC inverter. This inverter converts the generated DC power from different generators and storages to AC of the desired voltage and frequency to satisfy the AC user load demand. This inverter should be adequate to cover the peak load demands, while the back-up generator capacity (fuel cell generator) should be able to meet the peak load and charge the short term storage units simultaneously. it can be seen that each power source is connected to the DC bus-bar through its own DC/DC converter. The DC/DC converters which connect the battery or hydrogen fuel cell system to the DC bus-bar differs from the others by being bi-directional, instead of unidirectional, in order to allow charge and discharge of battery as well as hydrogen storage by electrolyser and fuel cell. These converters are used in order to produce a constant DC voltage on their outputs regardless of the voltage variations on their inputs. The advantage of this topology is that the load demand is satisfied without interruption even when the generators charge the short-term storage units. The design principles of this topology are rather easy to implement. Their serious disadvantage is low overall conversion efficiency. Furthermore, expanding the system by increasing a component capacities or adding further generators is very complicated due to the limited nominal capacity of the DC/AC inverter.

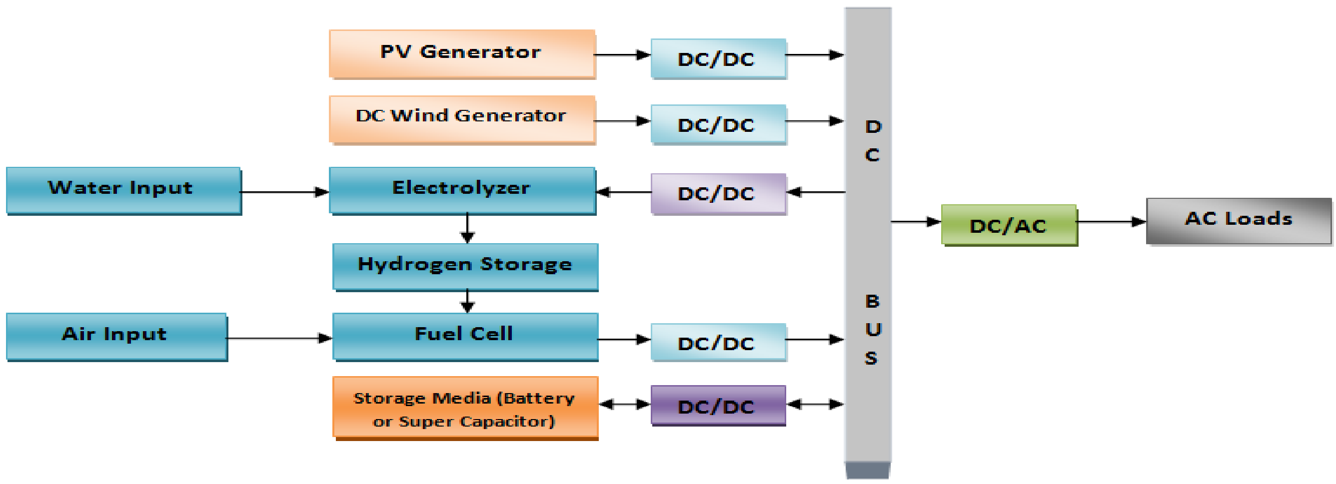

Fig.2. Block diagram of DC Coupled Hybrid Power System

B. AC Coupled System Topology:

All system components in this topology are connected to the AC user load via the AC bus-bar.The AC coupled system topology has a superior performance compared to the DC coupled configuration since each inverter can be synchronized to its generator so that it can supply the load independently and simultaneously with other inverters. This offers some flexibility for the energy sources to meet the user load demand. In case of low load demand, all the inverters of the generators and storages are in standby mode operation without one inverter, for example the PV generator inverter, to meet the load demand. However, during high load demands or peak times, some generators and storage units or all are operated in parallel to meet the user load demand. Because of this parallel operation capability, the capacities of the power conditioning units (PCUs) and the generators are reduced. This topology has several advantages compared to the DC coupled topology such as higher overall efficiency and smaller sizes of the PCUs. The operation and control of this topology are sophisticated due to the synchronization process required between the components. The development of an advanced PCU simplifies the control and the load dispatch problem. Therefore, advanced control algorithms which build and stabilize the isolated grid and allow parallel operation of different renewable and conventional generators as well as the integration of storage media have been developed. In this topology, the expansion or modification of the hybrid system configurations can easily be carried out in order to cover the demand growth or change in demand behavior.

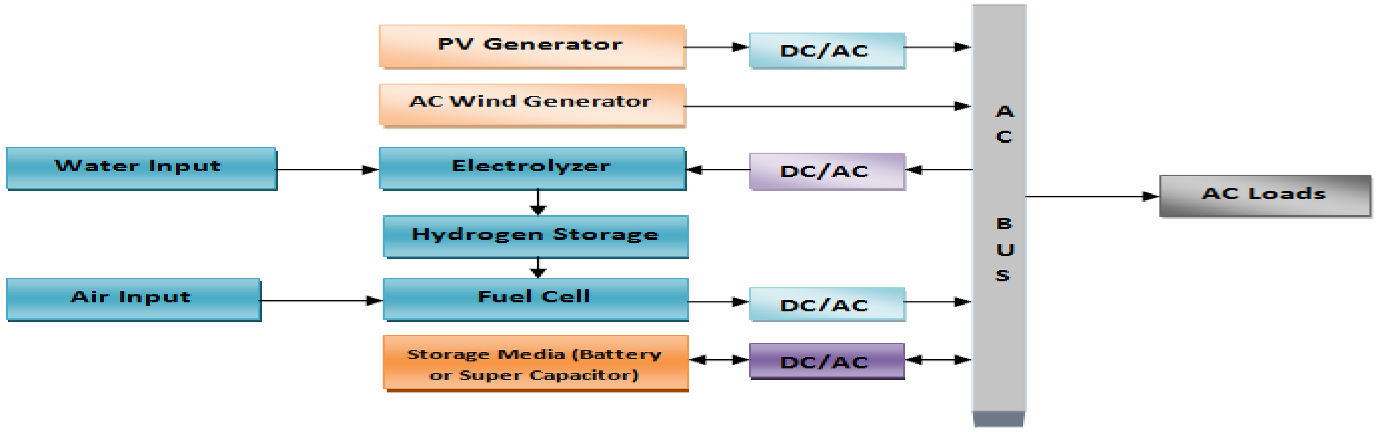

Fig.3. Block diagram of AC Coupled Hybrid Power System

C. Power Conditioning Units(PCUs):

Photovoltaic or fuel cell power systems, which generate power as a direct current (DC), require power conversion units to convert the power from DC to alternating current (AC). This power could be connected to the transmission and distribution network of a utility grid. There are other applications, where it is necessary to be able to control power flow in both directions between the AC and DC sides. For all these cases power conditioning units are used. Power conditioning units (PCUs) are defined generally as electronic units that transform DC power to AC power (inverters), AC power to DC power (rectifiers), both (bi-directional power electronic converters), or convert DC power at one voltage level to DC power at another voltage level.

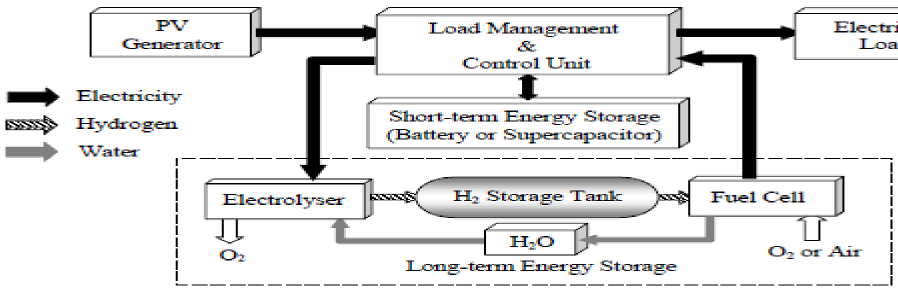

Fig.4. Concept of Hybrid PVFC System

V. GRID INTERACTIVE SYSTEM

In a grid interactive system,all excess power is fed to grid. Here the DC power is first coverted to AC by inverter and the AC power is stepped up to higher voltages using stepup transformer and fed to the grid.

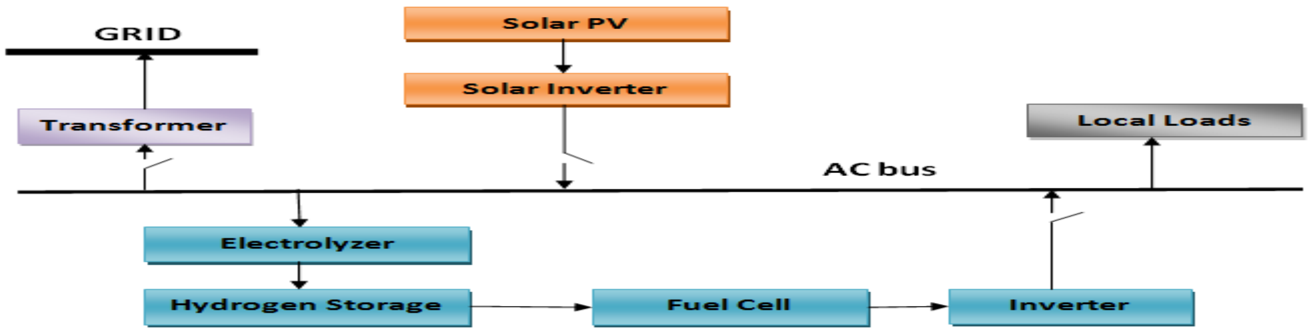

Fig.5. Block diagram of Grid interactive System

VI. Fuel cell vehicle and residential fuelling stations

The hydrogen stored can also be used for fuelling vehicles. A fuel cell vehicle (FCV) or fuel cell electric vehicle (FCEV) is a type of vehicle which uses a fuel cell to power its on-board electric motor. Fuel cells in vehicles create electricity to power an electric motor, generally using oxygen from the air and compressed hydrogen. A fuel cell vehicle that is fueled with hydrogen emits only water and heat, but no tailpipe pollutants; therefore it is considered a zero-emissions vehicle.

VII. Conclusion

Hybridization through combining different energy sources in one supply system offers the best possibility to use locally available renewable energies. The nature of hybridization is mainly based on the special features and economic potential of various energy conversion processes and on the power range. Hybrid system technology mainly covers stand-alone systems as well as isolated grids of small and medium power ranges. The modular hybrid power system coupling all generators, storage media and user loads on the AC side come out with numerous advantages, such as simplicity in system design, high reliability, and expandability. Moreover, the AC side structure provides standardization, quality assurance and serial production which also results in a considerable potential of cost reduction. Due to the features of modular expandability and general adaptability a family of hybrid systems in megawatt-range is initiated in order to cover a multitude of different stand-alone applications.

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