Simulation Model of a Hybrid Photo Voltaic/ Fuel Cell/ Ultra-Capacitor System for Stand Alone Applications

Mangipudi Sreedevi
Dept. of Electrical and Electronics Engineering
Coastal Institute of Technology & Management
Kothavalasa, Vizianagaram
Andhra Pradesh, India

Carmel Tensy Pereira
Dept. of Electrical and Electronics Engineering
Coastal Institute of Technology & Management
Kothavalasa, Vizianagaram
Andhra Pradesh, India

K. Jyothi Bojjamma
Dept. of Electrical and Electronics Engineering
Coastal Institute of Technology & Management
Kothavalasa, Vizianagaram
Andhra Pradesh, India

***Abstract*—A stand-alone power system is an autonomous system that supplies electricity to the user load without being connected to the electric grid. This kind of decentralized system is frequently located in remote and inaccessible areas with low population density lacking even the basic infrastructure. In this paper a hybrid model which couples a Photo Voltaic generator (PV), a water electrolyzer, a storage gas tank, a Fuel Cell system (FC) and an Ultra-Capacitor is used. The system is intended to be an environmentally friendly solution since it tries to maximize the use of renewable energy sources. Electricity is produced by a PV generator to meet the requirements of users. Whenever there is enough solar radiation the user load can be powered totally by the PV. During periods of low solar radiation, auxiliary electricity is required to meet the demand. A high pressure water electrolyzer is powered by the excess energy from the PV generator to produce hydrogen and oxygen. The FC consumes these gases and produces electricity to meet the user demand when the PV energy is deficient, so that it works as an auxiliary generator. If the rate of load demand increases the outside limits of FC capability, the UC bank meets the load demand above that which is provided by PV and FC systems. The integration of renewable energy sources to form a hybrid system is an excellent option for distributed energy production. The model is developed and applied in the MATLAB and Simulink environment based on the mathematical and electrical models developed for the proposed systems**

Keywords—Dynamic model, Photo Voltaic, Fuel Cell, Ultra-Capacitor

I. INTRODUTION

The concentration on the use of fossil fuels for energy supply is the main threat for the stability of the global climate system and our natural living conditions. To conserve our globe, the scientific community gave evidence that mankind has to decrease the green house emissions, like CO_2 and methane. In order not to harm our natural living spaces and threaten their resilience, a renewed compatibility would require a suitable form of energy alternatives sources that should be independent, easily accessible, and low in cost and should be environmentally clean.

Renewable energy, and in particular power generation from solar energy using Photo Voltaic (PV) has emerged in last decades since it has the aforesaid advantages and less maintenance, no wear and tear. The main application of PV systems are in either stand-alone systems such as water pumping, domestic and street lightening, electric vehicles, military and space applications or grid-connected configurations like hybrid systems and power plants.

PV generators directly convert solar radiation into electricity. Due to harmless environmental effect of PV generators, they are replacing electricity generated by other polluting ways and even more popular for electricity generator where none was available before. With increasing penetration of solar PV devices, various anti-pollution apparatus can be operated by solar power. The power generated by a PV system is highly dependent on weather conditions. For example, during cloudy periods and at night, the PV system could not generate any power. In addition, it is difficult to store the power generated by a PV system for future use. To overcome this problem, a PV system can be integrated with other alternate power sources and/or storage systems, such as electrolyzer, hydrogen storage tank[1 4 5], Fuel Cell systems and Ultra-Capacitor bank. The combination of FC and UC bank is an attractive choice due to their higher efficiency, fats load-response, flexible and modular structure for use with other alternative sources such as PV systems or wind turbines. The integration of renewable energy sources to form a hybrid system is an excellent option for distributed energy production. In order to efficiently and economically utilize renewable energy resources of wind and PV applications, some form of back up is almost universally required. Storage energy systems (SES) as battery banks or super capacitors are very important for solar-wind power generation systems.

An FC power plant uses oxygen and hydrogen to convert chemical energy into electric energy. Due to the low working temperature (80-100°C) and fast start up, proton exchange member (PEM) fuel cell power plants (FCPPs) are one of the promising candidates for residential and commercial applications [6]. In this study, A PEMFC power plant is preferred because, among the various types of FC systems, these power plants have been found to be especially suitable for hybrid energy systems[7]. Unlike a storage battery, which also presents an attractive back up option, such as fast response, modular construction and flexibility, the FC power can produce electricity for unlimited time to support the PV power generator. Therefore, a continuous supply of high quality power generated from the FC hybrid system is possible day and night. However, assisting the FC power plant with a parallel UC bank makes an economic sense when satisfying the peak power demands or transient conditions. UC's are electrical energy storage devices (a few Farads to several thousand Farads per cell) with high power densities when compared to batteries. Without the UC bank, the FC system must supply all power demand thus increasing the size and cost of the FC power plant. Besides this, overloading of FC systems may cause gas starvation thus decreasing its performance and lifetime. This paper focuses on developing a simulation model to design and analyze the overall system performance of a feasible PV/FC/UC hybrid system with residential use. The simulation model can be used not only for analyzing the PV/FC/UC hybrid system performance, but also for sizing and designing the hybrid system to meet the load demands for any available meterological condition.

II. INTRODUCTION TO THE HYBRID POWER GENERATION

An efficient energy storage system is required, to get constant power and the electrical energy delivered by the PV system has to be converted into capacitor or battery energy, which is easy to store. However, in such systems although the power fluctuations can be eliminated and the hybrid system operating well, continuous power flow to the stand alone loads cannot be guaranteed due to the lack of energy capacity of storage systems specially under worst climatic conditions, when the generated power from the hybrid system are completely absent or in the case of insufficient output power. The FC system as a promising alternative can be used as a back-up energy source for the hybrid generation systems. In this section, the dynamic simulation model is described for the proposed PV/FC/UC hybrid power generation system. The block diagram of the integrated overall system is shown in fig-1.

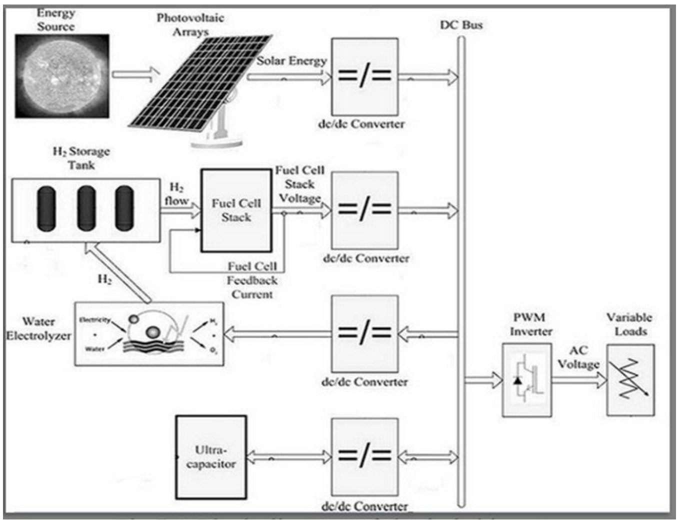

Fig. 1 Block Diagram of the proposed Hybrid System

Here, to sustain the power demand and solve the energy storage problem, electrical energy can be stored in the form of hydrogen. By using an electrolyzer, hydrogen can be generated and stored for future use. Recent advancements in hydrogen powered applications make hydrogen as an indispensable energy carrier for the hydrogen economy. In future energy systems, renewable energy sources will be used to generate hydrogen, and power demand might be satisfied using renewable sources and fuel cells in hydrogen topologies since the hydrogen economy is one vision of the future. The hydrogen produced by the electrolyzer using PV power is used in the FC system and acts as an energy buffer. Thus, the effects of reduction and even the absence of the available power from the PV system can be easily tracked.

A. *Structure of the PV system*

A PV cell is an electrical device that converts the electrical energy of light directly into electricity. When sunlight strikes the surface of a PV cell, the electrical field provides momentum and direction of light simulated electrons, resulting in a flow of current. The current output of the PV cell depends on its efficiency and size and inversely proportional to the intensity of sunlight striking the surface of the cell. The system consists of many such cells connected in series and parallel to provide the desired output terminal voltage and current. The performance of the PV system depends on the modules that comprise the system and the cells that comprise the modules. The performance characteristics of a PV module depend on its basic materials, manufacturing technology and operating conditions. This PV system exhibits anon-linear I-V characteristic. The operating point is defined by the intersection of the I-V characteristic with load line of the load connected to it.

Using the I-V cures, the P-V curves can be obtained to determine the maximum power to be drawn from the PV array under various short circuit current values. The maximum power output of the array varies according to solar radiation or load current. Therefore, a control system is needed to exploit the solar array more effectively as an electric power source by building a maximum power point tracker[11].

B. Maximum Power Point Tracker

There is a unique point on the I-V or P-V curve, called the Maximum Power Point (MPP), at which the entire system operates with maximum efficiency and produces its maximum output power. MPPT tracks for the maximum power independent of the environmental conditions and making the PV terminal voltage set constant at maximum value. The most commonly used method of MPPT; Perturb and Observe (P&O) method is implemented.

P&O MPPT algorithms are easily implemented in digital circuits. The terminal voltage and current of PV panels are determined and sampled to compute the output power and the result is compared with previous one to determine the direction of next perturbation. These methods have desirable adaptability to slowly fluctuating solar irradiation, temperature and variation of the PV panels. This is most economic, requiring only panel voltage and current measurements[8 9].

C. The Fuel Cell System

New power sources which have uninterrupted power supply and low emissions are required to meet the load demand in the present generation. FC's have the ability to fulfill all of the global power needs and environmental expectations. Therefore, they are considered as the power source for future. They are static electric power sources that convert the chemical energy of the fuel directly into electrical energy. They are made up of 3 segments: the anode, the electrolyte and the cathode. Two chemical reactions occur at the interfaces of the 3 segments. The net result of the reactions is that fuel is consumed, water or carbon dioxide is created, and an electric current is created, which can be used to power different electric devices (load). At the anode a catalyst oxidizes the fuel, usually hydrogen, turning it into a positively charged ion and a negatively charged ion. The electrolyte is a substance, specially designed so that ions can pass through it, but electrons cannot. The freed electrons travel through a wire creating electric current. The ions travel through the electrolyte to cathode. Once reaching the cathode, the ions are reunited with the electrons and the two react with a third chemical, usually oxygen, to create water or carbon dioxide.

The PEMFC has attracted a great deal of attention as a potential power source for automobile and stationary applications due to its low temperature of operation, high power density and high energy conversion efficiency.

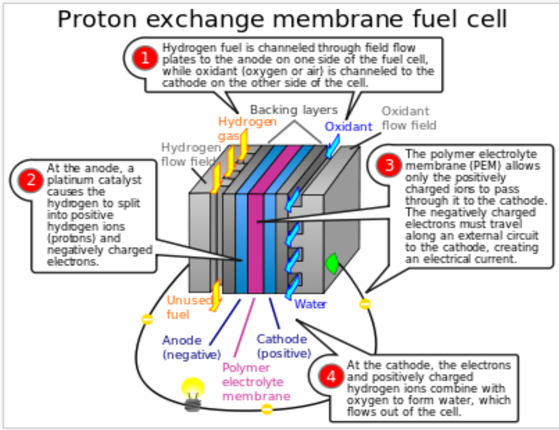

Fig. 2. Working of the PEMFC Stack

The FC system consumes hydrogen according to the power demand. The hydrogen is obtained from the on-board high pressure hydrogen tanks. During operational conditions, to control hydrogen flow rate according to the output power of the system, a feedback control strategy is utilized. To achieve this feedback control, the output current of the system is taken back to the input while converting the hydrogen into molar form. The main characteristics of the PEMFC stacks are that they produce water as residue, they have efficiency when compared to thermal generation, they operate at low temperatures which allows a fast start-up and improved dispatch ability, they use solid polymer as the electrolyte which reduces concerns related to construction, transport and safety.

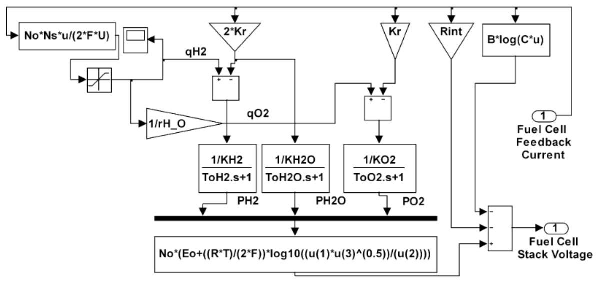

Fig. 3. Simulink Model of the FC system

D. Electrolyzer

In an electrolyzer water can be decomposed into its elementary components (hydrogen and oxygen) by passing electric current between two electrodes separated by an aqueous electrolyte. Standard alkaline water electrolyzer, which makes use of fossil fuel sources of electricity, is much cheaper than renewable electrolyzer, which makes use of solar or wind power sources of electricity. Although the environmental benefits of the renewable electrolyzer far surpass other methods, its use is not recommended in the short term. Renewable methods of electricity production are themselves a developing technology. The cost of hydrogen production from a renewable electrolysis is simply high to be economical. However, as a long-term goal, this production method is quite promising. The cost of the electrolyzer remains decreasing, as component materials continue to be changed and developed [12].

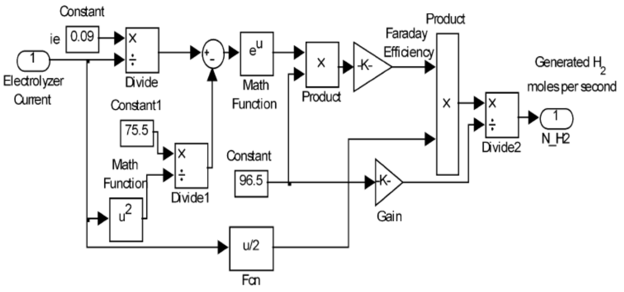

Fig. 4. Simulink Model of the Electrolyzer

E. Hydrogen Storage Tank

Hydrogen is not a primary energy source, but it is utilized as an energy carrier between power generation and power utilization. Power is generated from hydrogen either by conversion in a FC or by combustion in an internal combustion engine or turbine engine. It is characterized by low density so that its storage is difficult compared with liquid fuels.

Hydrogen can be stored either as compressed hydrogen gas or liquid hydrogen. Liquid hydrogen has been used as a fuel in space technology. It is light and has less potential risks in terms of storage pressure compared with compressed gas. The hydrogen liquefies to a colorless liquid at very low temperature and thus the storage tanks require sophisticated insulation techniques.

The amount of hydrogen required by the PEMFC is sent directly from the electrolyzer system based on the relationship between the output power and the hydrogen requirement of the PEMFC system. The remaining amount of hydrogen (the difference between the produced and consumed hydrogen) is sent to the storage tank[5].

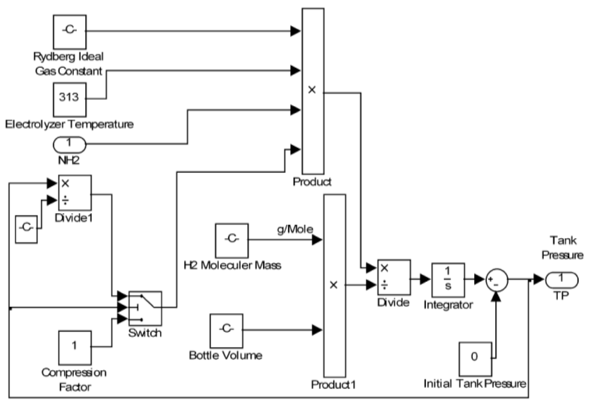

Fig. 5. Simulink Model of Hydrogen Storage Tank

F. Ultra-Capacitor

UC's store electricity by physically separating positive and negative charges different from batteries which do so chemically. The charge they can hold is like the static electricity that can build up the charge because of the extremely high surface area of their interior materials. An advantage of UC is their superfast rate of charge and discharge which is determined solely by their physical properties.

Such a device can be used in parallel with FC to reduce its voltage variations due to power variations. The UC can be modelled using a capacitor in series with a resistor. The model consists of a capacitance (C), an equivalent series resistance (ESR, R) representing the charging and discharging resistance, and an equivalent parallel resistance (EPR) representing the self-discharging losses. The EPR models leakage effects and affects only the long term energy storage performance of the UC[10].

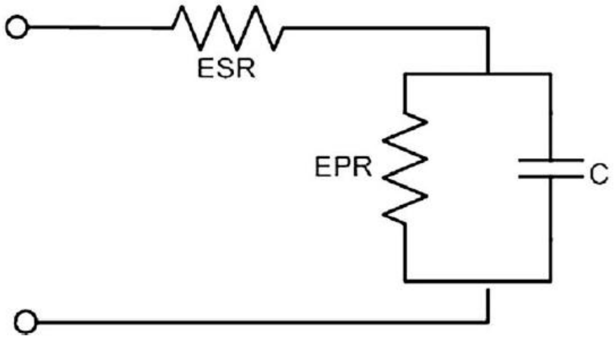

Fig. 6 Classical Equivalent Model for the UC Unit

When the UC bank is subjected to supply a prescribed amount of energy, its terminal voltage decreases. If the bank releases energy to the load side, its terminal voltage is positive. If energy is captured by the bank, it is negative. In practical applications, the required amount of terminal voltage and energy or the capacitance of the UC storage system can be achieved using multiple UC's in series and parallel. The terminal voltage determines the number of capacitors connected in series to form a bank and the total capacitance determines the number of capacitors which must be connected in parallel in the bank.

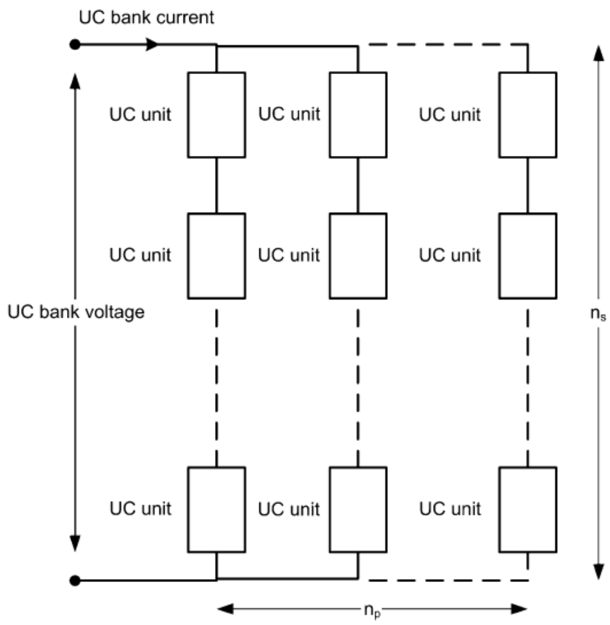

Fig. 7 Arrangement of Capacitors in an UC Bank

III. SIMULATION RESULTS

The characteristics of the individual components of the hybrid system are modeled in Simulink and the results are obtained as follows. Mathematical models of the system components are inter connected to form a general represenrtation of the whole system, through a central supervisory controller that defines the way in which components interact to simulate the operation of the entire system.

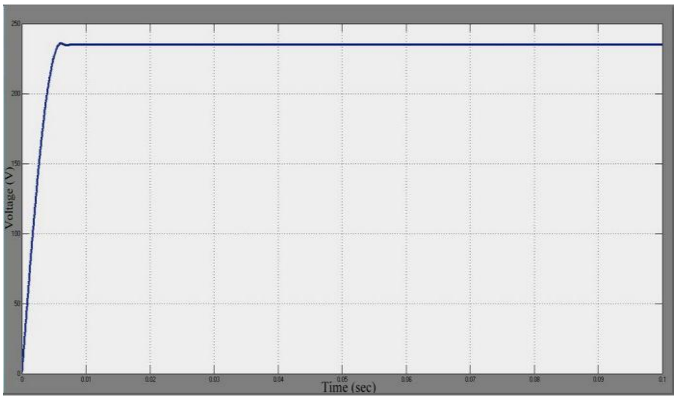

Fig. 8 DC output for the Proposed Hybrid System

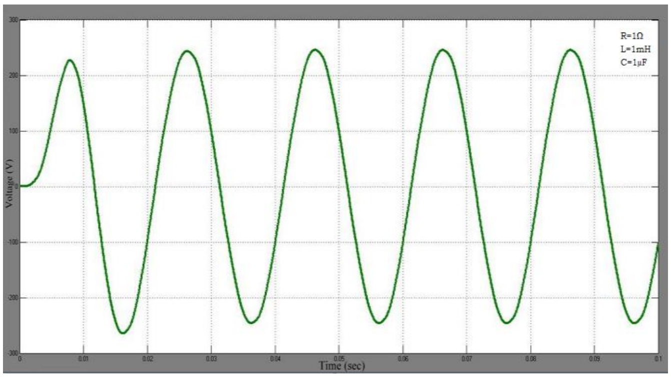

Fig. 9 AC output for the Proposed Hybrid System

IV. CONCLUSIONS

The main contribution of this paper is the hybridization of the renewable energy sources with alternate power sources using long and short term storage strategies with appropriate control strategy to build an autonomous system. The developed system and control strategy exhibit excellent performance for the simulation of a complete day or longer periods of time. Since the available power from the PV system is highly dependent on environmental conditions, an integrated model of the PV system with FC and UC system using a new topology is developed. A detailed simulation model has been developed which allows designing and analyzing any PV/FC/UC hybrid system with various power levels and parameters.

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