ISSN: 2454-4248
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Management of the Power Output of Photovoltaic Array and Fuel Cell

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Abstract— This paper comprises with the hybrid model of photovoltaic array (PV) and fuel cell (FC) for maximizing and managing the power generation in the system. In this model two different power sources had been used one is photovoltaic array and another one is fuel cell; both the sources are independent of their individual's working and can be used as per their requirement. The output generated by photovoltaic array and fuel cell is connected to the Cuk converter which regulates the voltage and providing constant dc supply at the output end of Cuk converter. Use of fuel cell in the model helps to compensate the photovoltaic array output during night time or cloudy weather. If demand is less than power supply than surplus energy is used to generate hydrogen from pure water which get stored in storage tank for future generation in fuel cell. Controllers are used to reduce steady state error, harmonics and output impedances.

***Keywords** - Fuel Cel; Photovoltaic Array; Cuk Converte; PI and PID Controller.*

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I. INTRODUCTION

Most part of energy is generated by fossil fuels and by some other non-renewable resources, these resources will eventually vanish. Moreover, it would become expensive to retrieve those vanishing resources. So, in order to conserve these resources, switch on some renewable resources which are easily available and inexpensive to generate the energy. On the other side, different types of renewable energy sources, for example, wind and solar energy, have no danger of being extinct as they are constantly renewed. Most of the countries are now using large solar power plant and hydropower plant to generate the electricity at very large scale [1] [2].

In this proposal, the photovoltaic array fuel cell and Cuk converter are used to generate the power using solar energy and hydrogen gas as a primary source respectively. In PV power generation, solar energy is directly converted into electric energy by using photovoltaic cell. This method of electricity generation is being followed as better alternative of non-renewable sources of electricity generation. This way of electricity generation is also feasible in remote locations where no other sources of electricity can be used. There are no moving parts in PV panels, thus operating silently without generation of harmful emissions. PV solar is the third energy source after wind and hydropower source [3]. More than 100 countries are now using solar PV. Although, electricity generation using PV is more reliable source of electricity, but it has large variation in output power produced on account of varying external weather conditions. Beside variable power generation, solar PV panels have very short lifetime because of frequent charge and discharge.

Another viable option is fuel cell (FC) which acts as the electrochemical device by transforming the chemical energy of a reaction of hydrogen and oxygen into electrical energy without use of heat engine. One of the main advantages of using FC is that generation efficiency is about 40% and has no harmful emissions. In case of FC, it is possible to increase the efficiency up to around 80% if we recover the exhausted energy of the cell. The performance of the proposed system is validated by running numerical simulation in MATLAB [4] [5].

II. SYSTEM CONFIGURATION

In this proposal, Hydrogen storage tank, Concentrator PV array, Electrolyzer, Cuk Converter, Fuel Cell stack (PEMFC), Transformer Less (TL) inverter and MPPT are used.

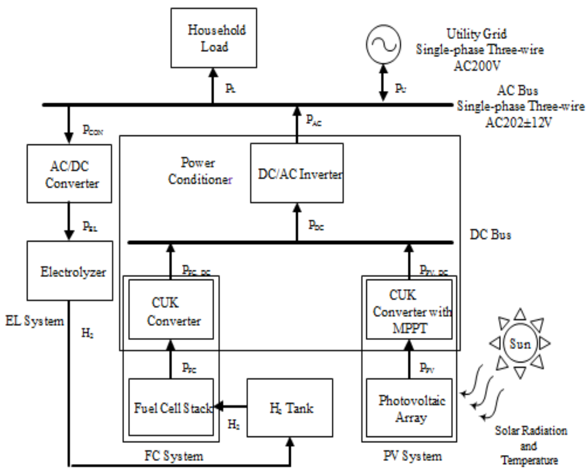

Fig.1. Hybrid System Structure

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A. Photovoltaic System

Photovoltaic system compromises of photovoltaic cells that transform solar energy into electrical energy. PV cells usually produce power smaller than 2W with around 0.5V DC. To get desired level of power and voltage rating, it is required to connect multiple PV cells in series-parallel topology. Single PV cells are connected with each other to form modules which are further connected to form PV array.

In this system, we used Concentrator photovoltaic (CPV); it employs lenses with curved mirrors to direct sunlight on the multi-junction solar cells. In addition, solar trackers and cooling system are used to further enhance the performance of proposed system.

B. Fuel Cell

A fuel cell works as an electrochemical cell which produces the transformation of chemical energy to the electrical energy by reaction of hydrogen and oxygen. Fuel cells differ from chemical batteries as they need a regular supply of fuel and oxygen to continue the chemical reaction, but, in the battery, chemical energy is produced from the chemicals stored in the battery [7-29]. Fuel cells act as the continuous source of electricity if it is continuously supplied with fuel and oxygen. Fuel cell comprises of two electrodes, one is named as anode and other is named as cathode, where chemical reaction occurs.

In this hybrid system, we used Proton Exchange Membrane (PEM) fuel cells. Besides being lighter and more compact, it operates at a lower temperature with 40–60% efficiency and it can also change the output to compete with power demands. It also offers the advantage of simpler maintenance owing to its simple structure.

C. Cuk Converter

It is essential to maintain the output voltage of photovoltaic unit and fuel cell. Therefore, the Cuk converter is used which smoothes the output current. Cuk converter is a DC/DC converter which produces output voltage higher or smaller than the input voltage. Normally, it behaves like boost converter and for making it a buck converter, capacitor is connected with it to increase its voltage. It employs a capacitor which works as the energy-storage element. It was named after Slobodan Cuk who first proposed its design. Cuk converter can either function in continuous or discontinuous current mode [30-46]. It can also function in discontinuous voltage mode because there is zero output voltage during the commutation cycle [47-72].

D. Transformerless Inverter

To convert the output of photovoltaic unit and fuel cell from DC to AC, we need inverter, so, we used Transformer Less inverter (TL). Transformer Less inverters are light in weight, compact in size, and comparatively inexpensive. It produces very less amount of heat and humidity in comparison to standard inverters on account of electronic switching rather than mechanical switching. TL inverters have the distinct capability of using two power point trackers which facilitates to consider the installations as individual Solar PV Systems. Or we can say that, solar PV Panels can be employed in two different directions using TL inverters, depending on the sunlight direction. It also facilitates generation of DC output during different peak hours with maximum output voltage. Traditional inverters use only one power point or one solar panel. It results into lower DC output voltage of complete system due to less performance of one single panel [6].

III. Control Strategies

A. Maximum Power Point Tracking (MPPT)

In this hybrid model, we used Maximum Power Point Tracking algorithm which controls the controllers to extract the maximum power possible from PV module under given conditions [6]. The point of voltage corresponding to which

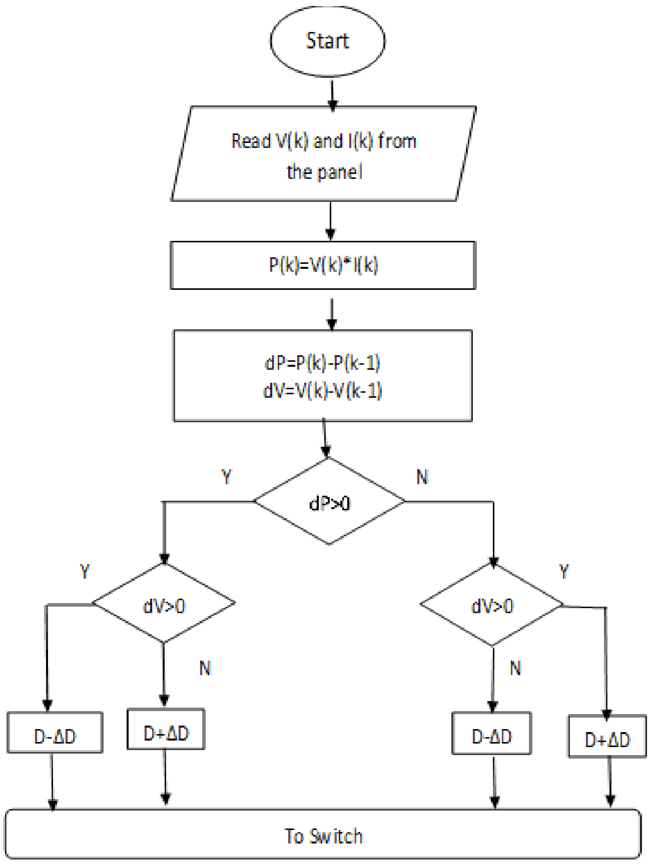

Fig.2. MPPT Algorithm

we get maximum power from PV module is called 'maximum power point' (or peak power voltage). There is direct relationship of solar radiation, ambient temperature and solar cell temperature with maximum power. MPPT checks and

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compares the PV module's output with the battery voltage. Depending on the comparison, MPPT decides the best power output of PV module for charging the battery and transforms the best voltage to the best current of the battery. MPPT can also give energy supply to a DC load linked with the battery. MPPT is considered as the most effective control algorithm under cold weather, cloudy or hazy days.

B. Fuzzy Logic Controller

Fuzzy control system works on continuous values ranging from 0 to 1, unlike classical or digital logic, which understands just 0 or 1 (false or true respectively), no value between them. Fuzzy logic was first purposed by Lotfi A Zadeh in 1965. The fuzzy rule is same as 'IF ELSE' rule preceded by a condition and then followed by the conclusion.

The basic structure of fuzzy logic controller is shown in diagram. The process of fuzzy logic controller is categorized into three stages; 1-Fuzzification 2-Knowledge base 3-Defuzzification. In fuzzification, exact inputs are converted into fuzzy values which are sending to knowledge base unit and processed with fuzzy rules. The output obtained after applying fuzzy rules is sent to defuzzification. The basic concept of this controller is to obtain the desired values as per the requirement.

C. PID Controller

PID controller is a controlled feedback mechanism. It computes the error, e(t) in terms of deviation between desired set points and actual output of the process in continuous manner. It then determines the correction required using the

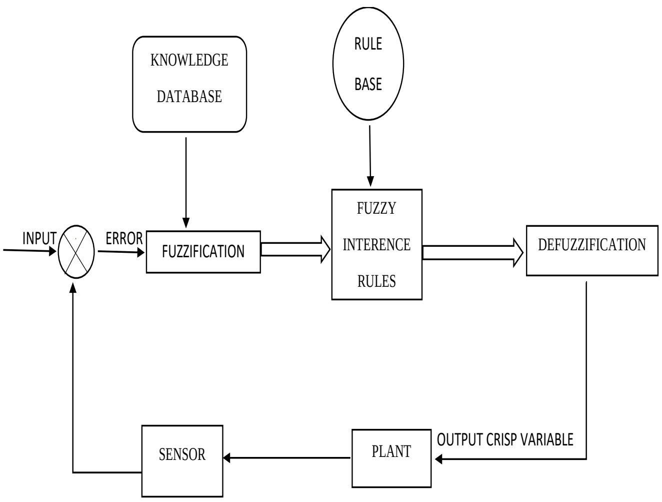

Fig.3. Fuzzy Logic System Structure

proportional, integral and derivative parts of PID controller.

$$u = K_p e + K_i \int_0^t e dt + K_d \frac{d}{dt} e$$

In a fuel cell, the pressure regulator regulates mass of H_2, at proper tank pressure H_2 and mass of O_2 (in) making the oxygen pressure of outlet at a desired back pressure of O_2 (bp), to ensure output power and output voltage matches the demand when the load varies

Design of PID controller depends on the mass of H_2 (in) and mass of O_2 (out) to ensure the output voltage generates smoothly.

IV. WORKING PRINCIPLE

This proposal comprises of hybrid model of PV and Fuel Cell. Solar PV power generation has become the most advantageous electricity generation technique in today's time. Though, during night and cloudy weather, there is much variation in the output. Other alternative if use of fuel cell but we do not use it as alone power generator due to its high cost. Hence, Fuel Cell only acts as a backup to PV System. Working principle has been classified into three parts:

A. Generation < demand

During bad weather or cloudy weather, the PV system cannot produce sufficient power to load due to which power output less than the power is demanded by load which makes the discontinuity in supply. So, to remove the discontinuity, PEM fuel cell is used which compensates power shortage. Fuel Cell uses hydrogen gas as a fuel and oxygen to produce electricity and water as a waste, then, this water is electrolyzed to make hydrogen to be stored in storage tank.

$$\frac{1}{2} O_2 + H_2 \rightarrow H_2O + \text{electricity}$$

The backup provided by fuel cell is for short time so to meet the requirement of load, preserved hydrogen gas is required. How preserved hydrogen gas is formed is discussed in third part.

B. Generation = Demand

During bright days enough power is generated which meets the demand i.e. generation = demand, no excess electricity is

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Table 1. Some significant developments in Photovoltaic and fuel cell

1839-1996	Energy was generated with the help of Photovoltaic cell on a very small scale and there was no energy storage system. Under cloudy weather energy generated by PV cell was unable to meet the demand [18].
2005	PV cell along with Diesel Generator set system was used to generate the energy. Problem of energy generation during bad weather condition was removed. But system was not economical [19].
2005-2010	Batteries were used to store the energy generated by PV cells for future use. The main problem of this system was that recharging of batteries required very long time and lifetime of batteries used were very short [20].
2012	PV with Fuel cell system was purposed. Power generation capacity was increased up to great extent. Its installation cost was high but running cost was very low [21].
2013-2014	Concept of super capacitor was given to compensate the slow response of Fuel cell and PV cell. Adaptive Proportional controller is used to regulate the load voltage which has increased the output voltage [22].
2014	Fuzzy logic based maximum power point tracking algorithm was used to track maximum power efficiently [23].
2015-2017	Research on separating hydrogen gas from water to make more economical energy generation from Fuel cell is being done [24].

generated in such cases fuel cell will not act as a backup. The electricity generated by the PV cell will meet the demand and fuel cell will not work in this case so no electricity is passed through the electrolyzer, therefore no hydrogen gas is stored in the tank.

C. Generation > Demand

During very hot days when high intensity radiation is projected on the PV cells, electricity generated is far more than the power demand of the load. The extra amount of electricity is passed to the electrolyzer. Electrolyzer has water stored in the tanks, now extra amount of energy is passed though the water which decomposes the water into hydrogen and oxygen.

$$2\,H_2O\,(l) \rightarrow 2H_2\,(g) + O_2(g)$$

Now this H2(*g)* is preserved in storage tank for future use. This preserved hydrogen gas acts as fuel for fuel cell this provide long time backup for PV when power generated by PV is less than power demanded by load as discussed in first part.

V. WORKING OF CONTROL CIRCUIT

The PV cells and FC generates the variable output voltages. So, a Cuk converter is employed which maintains the output voltage at a constant voltage. Now, this output voltage is compared with reference value to calculate the error signal and take corrective action by PID controller. The output of PID controller controls the pulse width modulation pulses with the adjusted duty ratio (Δ) so that output voltage can match the reference voltage. For higher output voltage, duty ratio (Δ) is greater than 50% and for lower output duty ratio (Δ) should be less than 50%.

The MPPT is employed in the Cuk converter so that maximum power could be extracted from the PV array under all weather conditions. The output is now connected to the dc link which is further connected to inverter. Inverter converts dc voltage to ac voltage, which is further supplied to the AC bus. From AC bus power is transferred to the household loads.

$$P = IV(1 - \Delta)$$

where, P is power generated, I is current in FC stack or PV cell, V is voltage of FC stack or PV cell.

The current of the PV array across the terminal is given by the equation given below:

$$I = N_p I_{ph} - N_p I_s \left(e^{\frac{\frac{q\left(\frac{V}{N_s} + IR_s\right)}{N_p}}{kT_c A}} - 1 \right)$$

I_{PH} = light generated current or photon current.
I_S = cell saturation of dark current.
T_C = cell's working temperature.
q = electron charge.
K = Boltzmann's constant.

VI. CONCLUSION

This paper presents the managing the power output of fuel cell and PV cell. Fuel cell act as backup or compensator to the power output of PV array. PID controller is used to generate the error signal so that output voltage can be regulated. The fuzzy logic controller is used to control the flow of hydrogen and oxygen in the FC stack. The proposed system facilitates flexibly by providing maximum solar energy and optimal energy from fuel cell. Till today the conversion power efficiency for small molecule in PV is 6.7%-8.94% and in case of polymer Organic Photovoltaic (OPVs) it ranges from 8.4%-10.6% while in case of perovskite OPVs conversion efficiency is 7%-21%. For economic efficiency research on hydrogen gas consumption for particular interval of time have to be done.

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