

Study of Hybrid Renewable Energy Photovoltaic and Fuel Cell System: A Review

Harpreet Kaur¹ and Inderpreet kaur²

¹Ph.D Research Scholar, Professor,
Electrical Engineering Department,
Chandigarh University, Gharuan, Mohali
harpreetchanni@yahoo.in,
inder_preet74@yahoo.com

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Abstract

Because of a consistently expanding interest for energy utilization and increasing public attention to the effect on earth, sustainable power source dependent upon Hybrid Energy Systems (HES) (for example solar, fuel cell and wind) to deliver power has fascinated increasing research interest. Photovoltaic (PV) energy systems are the main encouraging sustainable power source innovation arrangements. In contrast fuel cell (FC) is eco-friendly and noiseless as compared with hydrocarbon fuel-controlled equipments. It reserves fuel and is eco friendly for the earth. These frameworks can produce power from pure sources to deliver energy to loads situated in isolated territories. In this paper an extensive review of accessible hybrid PV-FC system is presented. This paper can help in choosing a particular goal based PV panel model out of several models available in literature.

Key Words : emission-free, hydrocarbon, sustainable, Photovoltaic, Fuel Cell

1 Introduction

Power is an essential ingredient of social development and economic advancement of a nation. Fossil fuel, for example, oil, coal and gas are generally utilized for power production on a huge level. Though, consuming fossil fuel is the main cause for ecological contamination, global warming and ozone layer consumption. Lately, sustainable power sources, for example, sun, wind, biomass, tidal et cetera have been focused by a developing natural attention to an unnatural weather change. Distributed Generation (DG) units utilizing renewable energy (RE) sources are produced to supply grid associated and off grid loads [1]-[2]. Extraordinarily, DG systems are built to deliver power to inaccessible territories [3]. Hybrid units utilizing sustainable power sources and diesel generators are well known for standalone utilization. Though, fuel shipping is only issue for distant areas. The intend of the hybrid system changes relying upon location area, capacity and in addition accessibility of the assets. Hence, overview on the specialized and financial suitability is required to choose the size, cost and adequacy [4]. Hybrid systems consolidate at least two sources of sustainable power source. It may be wind, hydraulic, photovoltaic or fuel cells [5]-[7]. Because of the alternatives of these sources, their blend gives constant electrical output [8]-[9]. The motivation behind a hybrid system is to fulfill the load demand by delivering as much energy as possible from inexhaustible power sources. It also incorporates a DC /AC converters, power molding and storage unit. Every one of these components may be associated with various models [10]-[12]. Energy saving is a predominant key and various storage techniques are utilized with hybrid units like thermal, mechanical, electrical, chemical or electrochemical. Recently there has been a fast increment in the utilization of sustainable power sources, specifically, solar and wind energy [13]-[15], because of the issues, for example, diminishment in non-renewable energy sources accessibility and natural issues. In practice to increment rated power and reliability, sustainable power sources are regularly joined with other power sources to arrange a hybrid energy conversion system for example, a PV/fuel cell (FC) hybrid system [16]-[18]. Figure 1.1 demonstrates a PV/FC hybrid system. It comprises of a PV subsystem utilized as the principle energy source and a FC stack which is normally utilized as a standby

energy source. This arrangement makes a hybrid PV/FC system highly reliable [19].

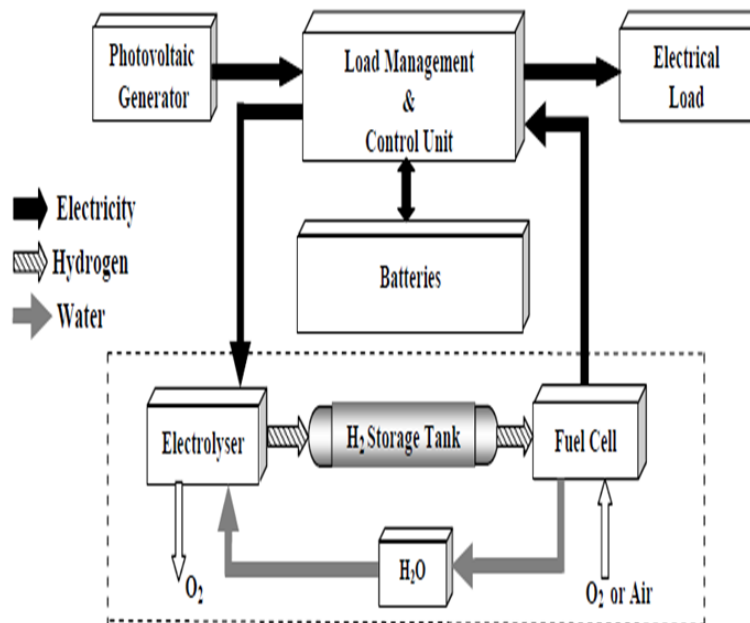


Fig.1.1. Hybrid PV FC system [1]

2 Literature Review

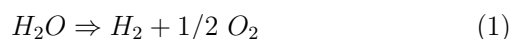
Ref.	HES components	Location	SA,GC	Description
20	SPV, WT, HFC, BT	India	GC	In this paper the domestic, industrial, agricultural, BTS load stack in a remote village was estimated. The essential load demand is around 250 kWh/day and 25 kWh/day and 12.7 kW peak. It has a load factor of 0.984. The average load is 15 kWh/day and has a maximum capacity of 25 kWh. The normal load is 1.2 kWh/day and has a load factor of 0.497. The consequences of this work NPC162, 987\$, COE 0.111 \$/kWh
21	SPV, HFC, BT	East Malaysia	SA	This paper concentrates upon operational technique and susceptibility investigation for ideal execution of the hybrid system. The HOMER optimization outcomes demonstrate that PV/Battery framework is cheap and eco- friendly with sum cost of \$ 335,297 and energy cost of 0.323 \$/kWh with no discharge.
22	SPV,HFC	Algeria	SA	This paper displays the modeling of PV/FC. It comprises of a PV generator, a PCU and PEMFC to deal with the system operation. When the solar generation is accessible, the electrolyzer is switched on for delivering Hydrogen to a storage tank. The delivered H ₂ is utilized by the FC stack and produces electrical energy to supply DC bus.
23	Wind,SPV,DG FC	China	GC	This paper builds up a multi-target improvement structure cost based , power proficiency and consistency models of the hybrid DG system, consisting of wind, solar and fuel cell production system. Detailed models for each unit were built up and given an effective method for hybrid system design.

24	SPV,Wind, FC,BT	Athens (NTUA)	SA	A novel autonomous sun based/wind/FC/battery vitality generation framework was formed and created. It in a perfect world unions sun oriented and twist energies with yield forces of a battery bank and an attractive PEMFC stack used as fundamental and discretionary autonomous power sources to convey energy needs in a detached zone.
25	SPV,FC, BT	Brazil	SA	This paper presented simulation model of a mix fuel cell/PV generator utilizing MATLAB/Simulink. The outcomes were displayed achievability of a solar hydrogen energy generation in a standalone system.
26	SPV,FC,	France	SA	This paper dealt with the perfect arrangement of an independent cross breed PV/FC control framework without battery storage to supply the electric load requirement of the city of Brest, Western Brittany in France. The proposed configuration revolved around prudent execution and was basically based on the loss of the power supply likelihood idea.

Table 1.1. Literature based on contribution of HFC & SPV in HRES

3 Overview Of Hydrogen(H_2)

Hydrogen (H_2) is the most normally accessible gasses on earth. Since H_2 is an unsteady component, it cannot be found in its pure form. On the other hand, water (H_2O) is a consistent source of hydrogen which covers around 66% of the world's surface. Hydrogen can be extracted from water energy by isolating hydrogen from oxygen (O_2). H_2 can be delivered by splitting water parts by means of electrolysis. Oxygen and Hydrogen obtained as per the compound reaction as shown in equation 1.



The full advantages from hydrogen as a sustainable fuel can be accomplished just when it is delivered from sustainable power sources. Wind and sun energy, as the most plentiful sustainable power sources, have encountered the best advancement during recent couple of years. Today, their technology is becoming finan-

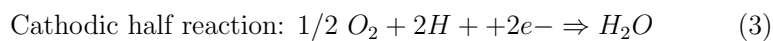
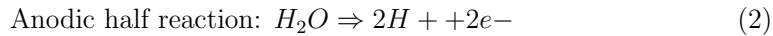
cially reasonable. Frequently these assets are broadly accessible, or maybe even the main accessible energy sources in some remote areas, and are regularly not coordinated with a grid. The operation of a wind or solar oriented system extremely depends on climate conditions and thus power generation is variable in time, and mostly the pattern does not comply with load demand. To satisfy the energy necessities during period of low accessible resources, energy should be stored [27]. The most well known approach to store energy is batteries, however they lose their energy content quickly and in this manner they can be just utilized over a brief span period. Batteries additionally have a constrained life cycle and issues with intensity of release, regularly requiring substitution of management. A superior choice may be to store as hydrogen which may offer the least peripheral cost of energy storage of any accessible technology. Different hydrogen technologies are shown in table 1.2.

H₂ production technology	Benefits	Barriers
Thermochemical cycles using cheap high temperature heat from nuclear or concentrated solar energy	Emission free production at low cost for industry or transportation	innovative work required more than 10 years on the procedure; materials, science innovation; high temperature atomic reactor, or sun powered
Electrolysis: splitting water using electricity	Monetarily accessible with demonstrated innovation; Well-comprehended mechanical process; particular; high immaculateness hydrogen, advantageous for delivering H ₂ from sustainable power.	Competition with direct use of renewable electricity
Gasification: part overwhelming hydrocarbons and biomass into hydrogen and gasses for improving	can be utilized for strong and fluid fills; conceivable collaborations with manufactured powers from biomass-biomass gasification being illustrated	Little units extremely uncommon; hydrogen typically requires broad cleaning before utilize; biomass has arrive utilize suggestions; rivalry with manufactured powers from biomass and still under research
Transforming (stationary and vehicle applications): hydrocarbon fuel with steam and heat	ease hydrogen from gaseous petrol; chance to join with extensive scale CO ₂ sequestration ('carbon stockpiling')	Little units not business; hydrogen contains a few pollutions - gas cleaning might be required for a few applications; CO ₂ emanations; essential fuel might be utilized straightforwardly

Table 1.2. H₂ production technologies [27]

4 Fuel Cell Working

An FC energy unit can be portrayed as a gadget which changes over the compound vitality and set away in hydrogen, or hydrogen-containing energizes, particularly into control, notwithstanding valuable warmth. Conventionally, power device essential parts are: positive terminal (fuel as anode), negative terminal (oxidant cathode). The molecule leading film is clubbed by the two terminals. For the most part a power device works by sustaining H_2 to the positive side and O_2 to the negative side. On the anode side impetus upgrades H_2 particles separately into protons and electrons. Electrons incident the outside circuit to deliver power while protons go off the film. On negative side, electron and proton assemble with O_2 for framing H_2O and releasing heat as shown in figure 1.2. The anodic half response; cathodic half response and the general response happens in the typical fuel cell can be summed up by the arrangement of responses demonstrated in eq. (2), eq. (23) and eq. (4) also clarified in [27] - [28].



The overall reaction:

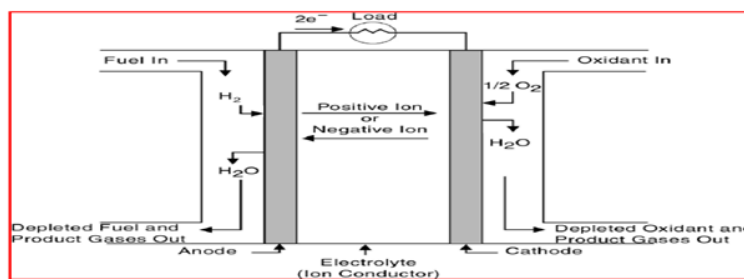
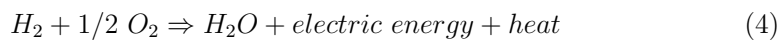


Fig 1.2. Fuel Cell diagram [27]

4.1 History of Fuel Cell

In 1839 FC was developed by an English researcher called William Grove [29]. After that there had been no perceptible examination until the 1960s, as soon as broad research started at NASA. A broad examination and inspection to create AFC and PEMFC for a space program was done by NASA (space lap ,Gemini, Apollo,) [29]. History of FC development is demonstrated in tabulation form (table 1.3).

The procedure of using electrical energy to break water was described by W. Nicholson and Carlisle	1800
fuel cell demonstration provided by William Grove	1835
Various fuel cell experiments by Separate teams:	1889
carbon batter constructed by W. Jacques	1896
Experiments conducted on high temperature devices by E. Baur and students	Early 1900's
PEMFC invented at GE by T. Grubb and L. Niedrach	1960s
Overall broad research on all types of fuel cell	1990s – Present

Table1.3. Fuel cell history [29]

4.2 Categorization of FC

Fuel cells are ordinarily grouped on the basis of material used as their electrolyte as shown in table 1.4. It decides many factors, for example, catalyst required chemical reaction, fuel used and operating temperature to create power. Thus all kind of FC is appropriate for various utilization

Temperature	High Temperature Fuel Cells			Low Temperature Fuel Cells		
Types	MCFC	SOFC	PAFC	PEMFC	AFC	DMFC
Power Range	Kilowatts/ megawatts	Kilowatts/ megawatts	Kilowatts	Watts/kilowatts	Watts/ kilowatts	Watts/ kilowatts
Fuel	Natural gas, coal	Natural gas, coal	Hydrogen	Hydrogen	Hydrogen	Methanol
Temperature Range	~ 650°C	800-1,000°C	~ 200°C	< 100°C	< 100°C	< 100°C
Electrolyte	Molten carbonate	Ceramic	Concentrated phosphoric acid	Proton-conducting membrane	Caustic potash solution	Proton- conducting membrane
Application Examples	combined heat power plants	Combined Heat Power plants	power stations	block-type heat, Vehicles, small generators, domestic supply,	external space	Vehicles, small appliances

Table 1.4. Fuel cell type summary [30]-[31]

5 Photovoltaic Cell History

"Photovoltaic" starts with the Greek word (phos) indicating "light", and "voltaic", which suggests electrical, from the name of the Italian physicist Volta, after whom a unit of electrical potential, the volt, is named. The enunciation "photovoltaic" has been being used since 1849 [33]. The PV cell is a gadget that converts sun powered radiation straight forwardly into DC electrical energy. The primary fuel photovoltaic anticipated that would deliver power is sunlight. The French physicist Alexander Edmond Becquerel lofty the photovoltaic effect in 1839. Regardless of the way that the essential sun based cell was made in 1883 by Charles Fritts, who secured the semiconductor selenium with thin layer of gold to shape the crossing points Charles' new gadget just fulfills capability of around 1% [33]-[34]. Even though broad research began in 1950, business generation did not start until the point that the 1970s after the oil crisis [35]-[36].

5.1 PV Cell Description

Exactly when daylight strikes a PV cell, the photons of the ingested daylight unstick the electrons from the molecules of the cell. The free electrons are compelled to experience the cell, making and filling in holes/openings in the cell. It is this progression of electrons

and openings that produces control. The change system of daylight into control is known as the photovoltaic effect. The electrons are animated to n-region (N-sort material), and the openings are dragged into p-sort material as appeared in figure 3. The electrons from n-area go through the outer circuit and give the electric vitality to associated stack [37]. Figure 3 displays the significant section of a PV energy framework. Since every cell is reliably making under 2 W at around 0.5 V DC, it is essential to interface PV cells orchestrated in parallel intend to convey the key power. Figure 1.4 exhibits how PV cells are connected together to diagram modules and how modules are identified with influence to array. There are no tenets on the measure of a module or array. A module can be measured from a couple of watts to hundered watts. Power rating of cluster can change from a couple of watts to megawatts [37]- [38]. Figure 1.4 shows the arrangement of activity of PV cell, module and array.

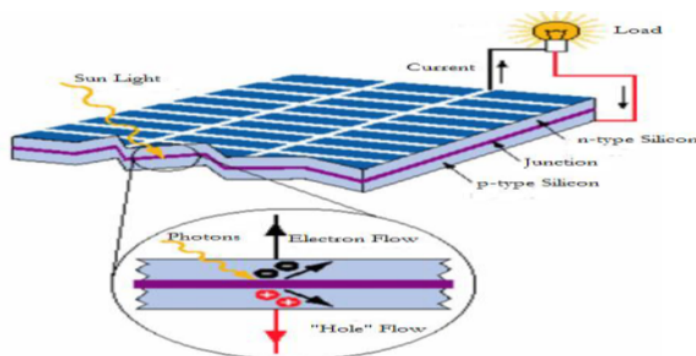


Fig1.3. Photovoltaic effect in a solar cell [37]

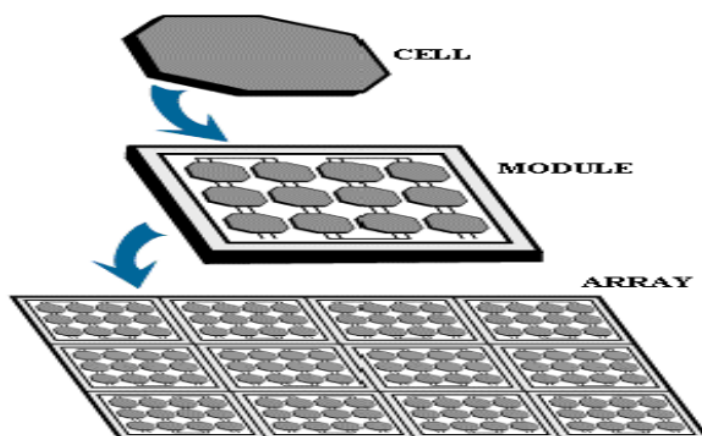


Fig 1.4. PV cell module and array [37]

5.2 Classification of Photovoltaic Technologies

PV can be divided into two fundamental classifications on the basis of technique utilized for assembling PV cells. Chiefly, crystalline silicon is the most regularly utilized technique to develop PV cells; and thin film, it is new developing and challenging technology. Figure 1.5 outline accessible PV cells techniques in the market. Table 1.5 demonstrates solar cell output for various PV technologies. Solar cells are considered as one of the unique sources of sustainable power source appropriate for vast scale reception in a carbon-compelled world and can add to decreased dependence on energy imports, while enhancing the security of energy supply. Another entry in the group of solar cells advancements is the natural inorganic halide perovskite. The real push for embracing these new solar cells relates to their potential as a financially and ecologically reasonable choice to conventional silicon-based technology [39]. Perovskite solar cells (PSCs) have recently emerged and known as "third generation solar cells" which have been generally advanced as a financially and ecologically practical sustainable technology choice to customary solar cells advances for tending to worldwide difficulties in energy generation, security and natural effect [40].

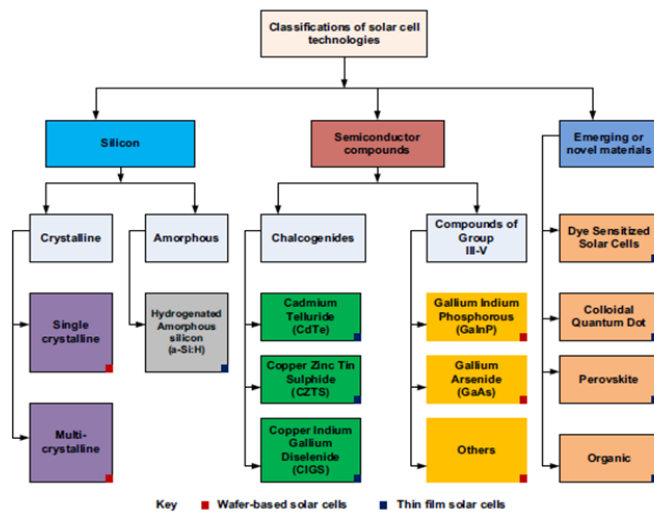


Fig 1.5. Solar cell Classification[39]

Cell kind	Normal Result %	Efficiency % (Maximum)
Mono crystalline (sc-Si)	15 - 20	23.4
Amorphous silicon (a-Si)	6 - 8	8.3
Multi crystalline (mc-Si) (Poly-crystalline)	13 - 16	17.3
Micromorph silicon ($\mu\text{m-Si}$)	9 - 11	12
Copper indium(gallium)	10 - 10	12.2
Cadmium telluride (CdTe)	8 -10	10.9
Dye sensitized solar cell	4 - 8	8
Organic solar cell	2- 5	5

Table 1.5: solar cell Efficiency[39]-[40]

6 Description of Different Hybrid Power System Configurations

6.1 Photovoltaic-Battery-Diesel Hybrid System

It requires essential budgetary hypothesis to design solitary PV framework that is adequately sizeable to make due in the hardest atmosphere conditions. Consequently, a joined PV framework can

offer a more practical option. With a particular ultimate objective to propel the framework plan and upgrade its openness, a diesel generator and battery bank could be related with the framework. At the time when the PV generator can't meet the principal control or amid requesting atmosphere conditions, the diesel generator can contribute the basic differentiation to ensure a certified power supply and revive the batteries meanwhile. Amid low load request, the PV structure will stimulate low batteries [41].

Disadvantages	Advantages
Batteries must be well stacked will arrival power with a great yield.	Diesel generators Might be worked Furthermore administered Eventually Tom's perusing a real and only an unfit populace.
Batteries transform hazardous gasses for example, H_2 and O_2 , around there they might a chance to be hazardous restricted puts.	Maintenance, consumables Further more extra parts would by accessible.
Diesel generators need an awful yield rate of force required (approximately 40%).	Batteries need arrived at a paramount development level.
Batteries need a moderately short lifetime contrasted with different framework segments.	Propelled battery innovations rapidly turning into economically accessible.

Table 1.6. Disadvantages and advantages of Photovoltaic-Battery-Diesel Hybrid System

6.2 Photovoltaic-Battery-Fuel cell Hybrid System

In this system FC displaced those diesel generator and other separate parts and courses of action are unalterably. FC in this structure will make used to revive those batteries and compensate the force insufficiency In whatever perspective PV can't meet well from claiming energy demand. PV/FC will be an guaranteeing schem[42]. Furthermore will be depended upon to displace PV/Diesel HPS in future. FC need a lot of people focuses of enthusiasm over diesel alternately petrol generator Concerning illustration summarized such as shown in table 1.7 .

Disadvantages	Advantages
The high capital cost of FC is thought to be its primary detriment. Nonetheless, FC cost is required to diminish later on as FC is delivered in large scale manufacturing	FC is ecologically well disposed, with low or even zero carbon outflows and low clamor level
	High vitality transformation proficiency of up to half contrasted and low diesel generator productivity of around 8 to 15 %.
	Lower operation and upkeep cost, because of negligible turning parts
	FC can work at fractional load while keeping up great effectiveness, while diesel generator can just work on the evaluated stack.

Table 1.7. Disadvantages and advantages of Photovoltaic-Battery-Fuel cell Hybrid System

6.3 PV-Electrolyzer-FC System

In this structure, the abundance energy is put away as packed hydrogen by means of transformation through the electrolyzer. The fuel cell is utilized to deliver power if the load power exceeds that created from the PV generator. It can likewise work as a calamity generator, if the PV generator system fails. With an aggregate productivity of the storage system in the scope of 50%, an appropriate storage volume can be accomplished and the PV generator capacity can be reduced fundamentally. This remunerates in part the additional cost of the hydrogen system. Distinctive system topologies have been utilized. Most normal is the DC association of PV generator, electrolyzer and fuel cell with, or even without, a DC/DC converter. Actually, this framework would possible be able to store the hydrogen as well as the oxygen. Because of safety issues and additional costs, the oxygen is not utilized and the fuel cell might be worked with the oxygen from air. Batteries and energy segments contain a remarkable potential to go down extraordinary photovoltaic power instabilities under extreme atmosphere conditions [43]-[44].

7 Results And Discussions

Hybridization through joining distinctive energy sources in a single supply system offers the best probability to utilize locally accessible

sustainable power sources. The idea of hybridization is essentially based on extraordinary highlights and financial capability of different power transformation forms and on the power range. Sustainable power source system with most recent innovations and types were summarized. Three distinctive structure arrangements were examined and compared. They are: 1. Photovoltaic-Battery-Diesel Hybrid System, 2. Photovoltaic-Battery-Fuel cell Hybrid System and 3. Photovoltaic-Electrolyzer-Fuel cell System. It is discovered that Photovoltaic-Electrolyzer-Fuel cell System is the best one with the most minimal cost of energy because of the high solar radiation level. Table 1.8 demonstrates correlation of 3 Hybrid Electric Power System [44]-[46].

Type of HEPS	cost	maintenance	reliability	runtime	pollution	life
Photovoltaic-Battery-Diesel Hybrid System	High	High	High	long	Yes	long
Photovoltaic-Battery-Fuel cell Hybrid System	Low	high	High	Short	Yes	short
Photovoltaic-Electrolyzer-Fuel cell System	low	low	High	Long	NO	long

Table 1.8 Comparison of 3 Hybrid Electric Power System [45]-[46]

7.1 Simulink Model of PV-Electrolyzer-FC System

As per the above discussion the Photovoltaic-Electrolyzer-Fuel cell System is considered the best option as compared to other two systems as shown in table 9. So the PV-Electrolyzer-FC System is chosen for modeling and simulation using MATLAB/SIMULINK for a specified data as given in table 1.9. The proposed model is shown in figure 1.6.

PV System	Rated power	120W/panel
	Total rated power	2.4kW
	Temperature	25°C
Electrolyzer(PEM)	Rated power	2.8kW
	H ₂ flow rate	8slpm
	Output Power	14atm
H ₂ storage	Tank volume	50m ³
	Tank pressure	150-200atm
	Compressor pressure	200atm
Fuel cell	Rated power	1.9kW
Battery(Lead-acid)	H ₂ Flow rate	15slpm
	Energy capacity	28kWh
Load	Equivalent hours	12hrs
	power	1-2kW

Table 1.9. System component sizing used in simulation

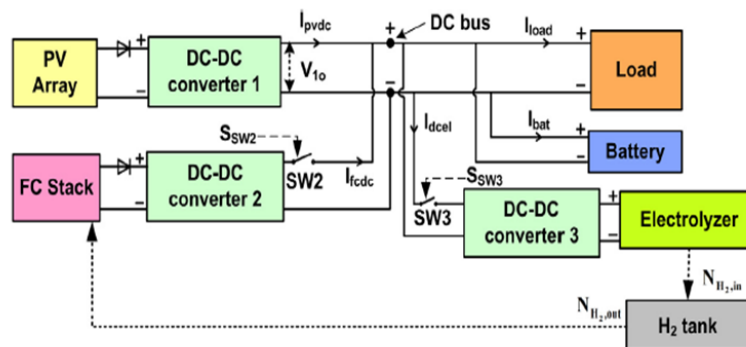


Fig 1.6 .SIMULINK model Schematic PV-Electrolyzer -FC-Battery Hybrid system[47]

7.2 Results

After simulation of the proposed model, the following results are obtained (figure 1.7): Current is 35.5 amperes, Battery voltage and load voltage is 11Volts.

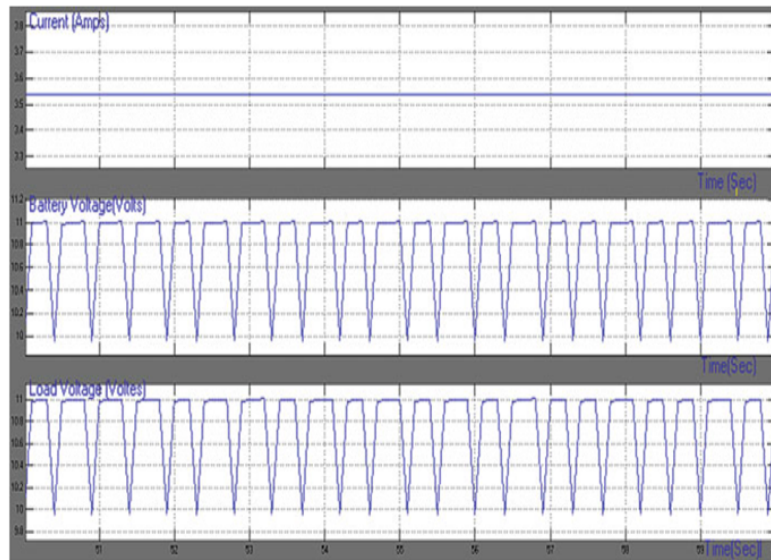


Fig 1.7. Scope wave forms of complete circuit [47]

8 Conclusion

It has been concluded that the performance of Photovoltaic-Electrolyzer Fuel Cell-Battery Hybrid system is better as compared to Photovoltaic-Battery-Diesel Hybrid System and Photovoltaic-Battery-Fuel cell Hybrid System.

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