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RESEARCH ARTICLE - ENGINEERING

Energy Management Strategy for PV PSO MPPT / Fuel Cell/Battery Hybrid System with Hydrogen Production and Storage

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Abstract

Due to the high uncertainty of renewable energy sources, and the diversity of energy sources and storage systems, it is mandatory to seek a controller that manages all these renewable energy sources and this hybrid energy storage. This paper proposed a renewable energy management system using flatness control and PID and PSO technologies that track the maximum power point from the PV array and manages the energy storage elements. Two energy storage are adopted: battery storage and hydrogen tank. The proposed (Nero-fuzzy) controller also works to fill the hydrogen storage tank wisely and safely by controlling the alkaline electrolyzer and the tank's pressure. The main aim of this combined system is to attain power stability. Since the PV is the primary production source, a PSO MPPT is a proposed system for optimum power delivered by the PV under different radiation and temperature conditions. The fuel cell has been used to compensate for the energy lost when there is a lack of control due to weather conditions or high-power demand by the DC load. A battery was coupled to the DC bus to respond quickly to the power requirement. When the radiation intensity is 1000 W/m^2, the PV will generate enough 18 kW to supply the load, run the electrolyzer 7 kW, and charge the batteries. While in the radiation change, when it is 240 W/m^2, the solar panels produce (4.3 kW) and the load (4.7 kW). The battery works first because of its quick response, and then the fuel cell works to generate instead of it, which is sufficient to operate the load only. The results show a stable and fast response grid under different weather conditions and load scenarios.

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Keywords: Alkaline Electrolyzer; Energy Management System (EMS); Hybrid Power System (HPS); Fuel Cell; PSO MPPT.

1. Introduction

Pollutants are increasing in the atmosphere due to the increasing demand for energy produced from coal, crude oil, and natural gas, the lack of these sources in some countries, and the high prices due to wars. Therefore, energy is produced from renewable energy sources (RES). Renewable energy sources, such as solar photovoltaic (PV) and wind turbines[1], are under development but are becoming more and more used due to their low cost and abundant availability in nature [2]. Many developed and developing countries use PV systems for various purposes. The world's population uses only 1/10000 of the solar energy available on the Earth's surface as its primary energy source. Solar Energy, if harnessed properly, could become powerful enough to meet the energy needs of future generations[3]. PV can be used of any size, from the smallest devices to the most significant power stations, and is easy to integrate into existing power systems [4].

On the other hand, PV systems are highly weather dependent. For example, a photovoltaic system will not produce any electricity if it is overcast or dark outside at that time. Solar irradiation and temperature changes are the leading causes of energy fluctuations in the photovoltaic (PV) system. Therefore the energy provided by the photovoltaic (PV) system is stored as backup energy [5]. Hybrid power systems with efficient energy management are the optimal solution to this challenge. Two or more power sources, transducers, and storage devices are used in hybrid power systems (HPS). HPS primarily aims to integrate energy sources and storage technologies. To increase system reliability and achieve better efficiency [6]. Recent developments in Fuel Cells have shown great potential and are considered an essential energy source for the future. A fuel Cell (FC) is a stationary energy source that uses electrolysis to produce energy from hydrogen. Unlike diesel generators, the Fuel Cell (FC) system has much higher reliability and almost no noise or moving components. Its adaptability, zero harmful emissions, fuel flexibility, and superior quality are features of the Fuel Cell (FC). The design simulation of a composite hybrid photovoltaic fuel-cell production system that uses an electrolyzer to generate hydrogen and a battery to store it can be found at[7]. An ELZ/FC generator hybrid system's performance

Nomenclature & Symbols			
CEM	Control Energy Management	PEMFC	Proton Exchange Membrane Fuel Cell
ELZ	Electrolyzer	PFC	Fuel Cell Power
FC	Fuel Fell	Pnet	Net Power
HPS	Hybrid Power System	PL	Load Power
HTP	Hydrogen Tank Pressure	PPV	Photovoltaic Power
MPPT	Max Power Point Tracking	PSO	Particle Swarm Optimization
PELZ	Electrolyzer Power	SoC	State of Charge

has been outlined.[8] PV/FC/Wind Hybrid System Design for Effective Energy Management[9]A hydrogen-storage wind power system is simulated in this way[10]. The author created a management system for FC[11].

The hybrid DC/DC microgrid's interlinking converter was intended to provide an autonomous control method. The work that was done in. The proposed system is simple and used efficiently. The hybrid system's dynamic behavior and performance are examined in [12]. Photovoltaic PV resources make up the hybrid system, which is hybrid-connected. With a suitable power management strategy and the use of Maximum Power Point Tracking (MPPT), this system harvests the most energy from the PV array. Modeling Particle swarm optimization (PSO) technology and analyzing the findings demonstrated that hybrid systems responded well to changes in solar irradiation. Modeling and management of a photovoltaic/battery/fuel cell hybrid producing system were given in[13]. There are two elements to the entire project. The researchers examined the subsystems in the first section, identifying several parameters for each. Voltage and current sensors, among other things, were the focus of the second section. Similarly, other writers concentrated on (HPS) in various aspects, such as the optimization of size and cost[14], management of power [15], and quality and dependability of electricity. In the work that was done in [16] Managing a hybrid PV/FC/SC/battery system, Where there is no production and storage of hydrogen, the primary objective of the research paper is to provide a continuous supply to the load using a dry alkaline electrolyzer for hydrogen product feeding the Fuel Cell (FC) with a rated power of 6 kW All of the studies above have certain flaws. For example, some researchers focus on long-term storage mediums, while others incorporate short-energy systems in their investigations. PV power control is described by some writers, while others seek to deal with energy management (EM) without offering power sharing across various energy sources and storage systems. In addition, several writers relied on computer simulations of solar irradiance, temperature, and weather patterns to back up their findings. Solar PV, PEMFC, lithium-ion battery, and ELZ are all included in this work's hybrid power system (HPS). The suggested controller (CEM) successfully controlled all of the energy sources and storage systems based on weather patterns and demand. The method is recommended to ensure the day's stable and reliable power supply. The combination is best for maximizing output energy, ensuring power continuity, and reducing output power fluctuations. This paper proposed a renewable energy management system that tracks the maximum power point from the PV array and manages the energy storage elements. The structure of this document is as follows: Section 2 focuses on the system's description. And illustrates how the system components are controlled. And Section 3 contains the simulation findings, while Section 4 concludes the discussion.

2. Methodology

A DC bus forms the basis of the whole system. The architecture of the DC bus consists of PV, PEMFC, ELZ, and battery, and the power conversion and transmission happen via the system in control energy management, as shown in Fig. 1.

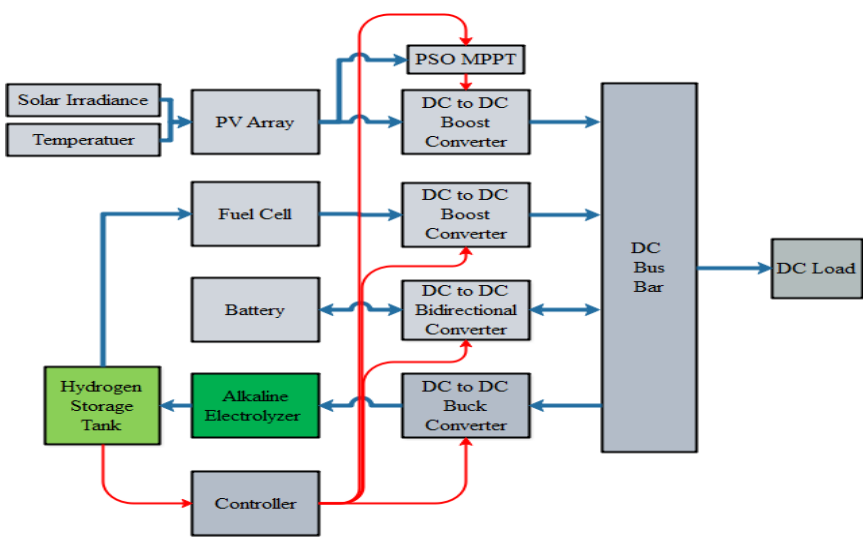

Fig. 1. Block diagram for the proposed system

DC-DC boost converters control and modify the output voltages of the PV and PEMFC. A constant voltage can be achieved through the use of Flatness control and PID technologies, to use the flatness control for our system, it is always feasible to define all state and all control variables of the method according to the flat output variable and a finite number of its derivatives, and The PSO strategy was implemented as well to maximize the quantity of energy that could be harvested from solar radiation and used for DC loads

A buck-boost converter transfers power from the battery to the rest of the system in both directions. Proportional Integral (PI) controllers are used to regulate the buck-boost converter. Even if only one power source is available, the DC bus output supplies the necessary power to the grid, as shown in Fig. 2 and the controller in Fig. 3.

A system simulation is performed to evaluate the performance of the proposed CEM. I am using data-driven simulation models for each PV and load model, as shown in Fig. 4.

2.1. The Controller Structure

The central controller includes five sub-controllers. The first sub-controller is responsible for tracking the maximum power point using the Particle Swarm Algorithm. The second user controls the electrolyzer voltage based on the gas pressure in the hydrogen storage tank and the energy availability, while the third controls the fuel cell output. The fourth sub-controller is responsible for charging and discharging the battery. Finally, the fifth regulates the fuel cell's output voltage.

2.1.1. PV MPPT controller

Photovoltaic Energy depends on the intensity of incident radiation and temperature, which are affected by weather fluctuations; therefore, to find the maximum power point for solar panels, (PSO) technology is adopted. The PSO algorithm adopts a set of solutions candidates for optimization. This approach (PSO) is a swarm of particles that may flow through parameter space and choose the paths that are affected by their best widths and the performance of their near neighbors. Because photovoltaic (PV) arrays have many vertices in the voltage and current characteristic curve, traditional maximum power point tracking (MPPT) control methods fail in partially shaded environments. Particle crowd optimization (PSO) technology is an excellent option for dealing with problems of varying severity. To eliminate the power fluctuation and keep the output power stable. The simulations in Fig. 5 show that the proposed model works very well.

2.1.2. Electrolyzer Controller

The input power of the Electrolyzer depends on its input current. A buck converter is used to regulate the input current of the Electrolyzer, which consequently controls the output power. The buck converter is controlled by a PI controller, as shown in Fig. 6.

2.1.3. PEMFC Controller

PEMFC is connected to the DC bus by a boost converter to regulate the voltage. This DC Bus is also supplied with solar panels and batteries as required. The PI controller is adopted to increase the fuel cell voltage's raise time to get the system's best performance, as shown in Fig. 7.

2.1.4. Battery Controller

A bidirectional DC-to-DC convertor is used to pass the energy to the DC bus. Works to raise the voltage in the case of discharge. feeding from the battery. And lowers the voltage in the case of charging (energy storage). In both cases, the control is via PWM for the two switches(S1&S2) shown in Fig. 8.

2.1.5. Hydrogen storage tank pressure controller

A neuro-fuzzy Controller controls the Hydrogen Storage Tank. This controller combines two methods based on artificial intelligence techniques: artificial neural networks and fuzzy logic. Calculating the hydrogen pressure safety is implemented using synthetic neural fuzzy heuristics systems, as shown in Fig. 9. The system shuts down as soon as the tank pressure reaches the set level.

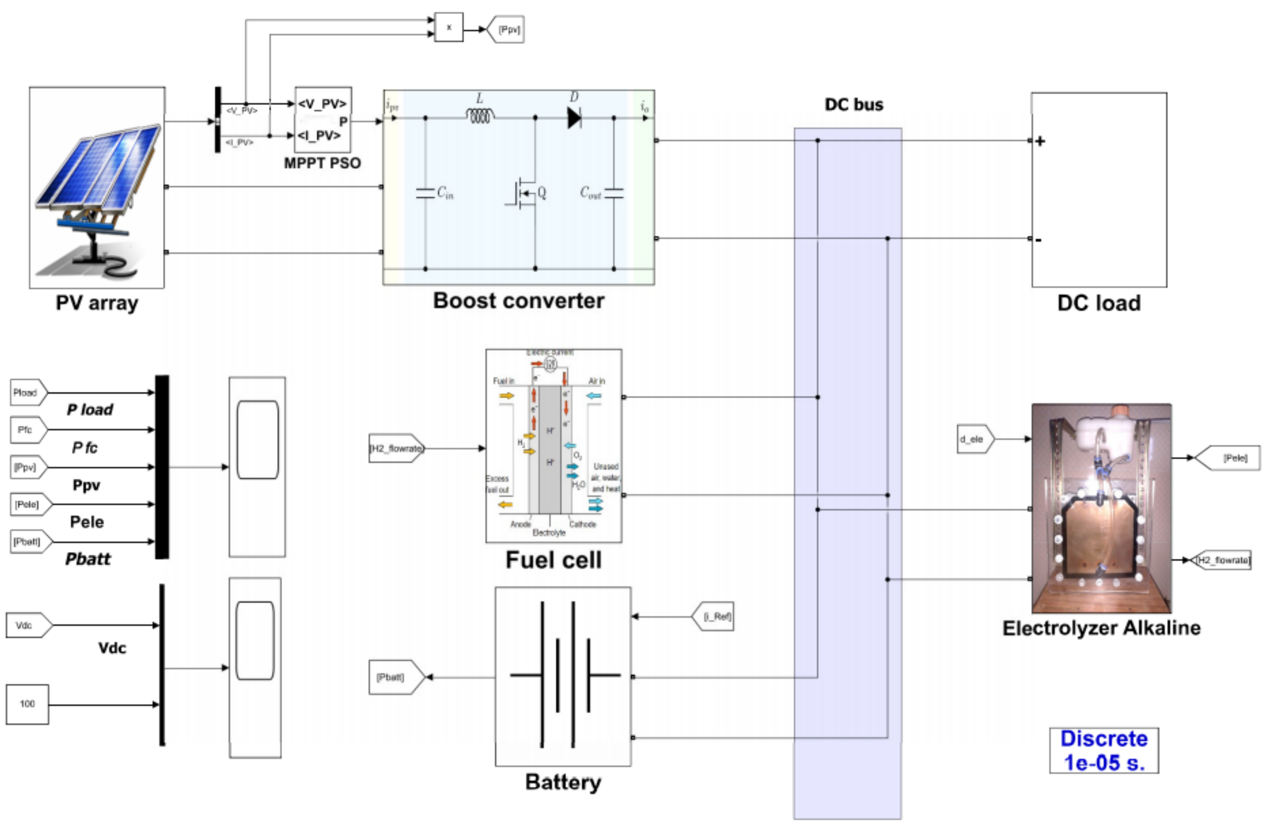

Fig. 2. Simulink for the proposed system

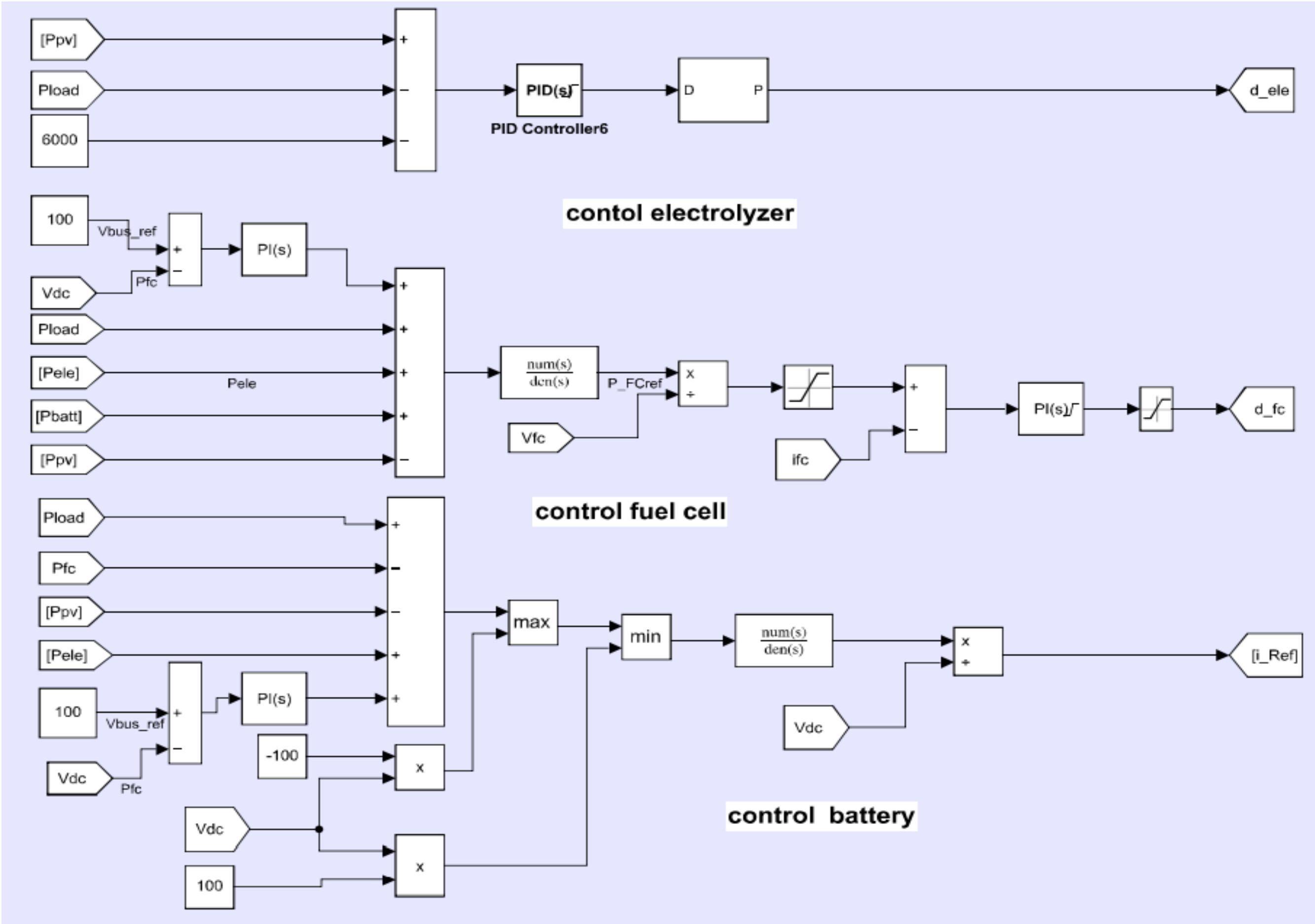

Fig. 3. The proposed hybrid energy controller

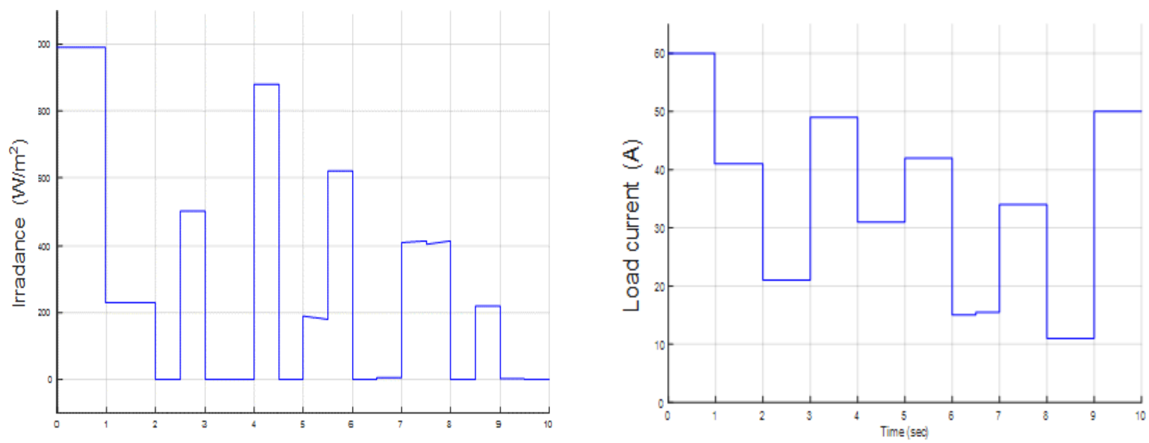

Fig. 4. Different Solar Irradiation and Variable Loads

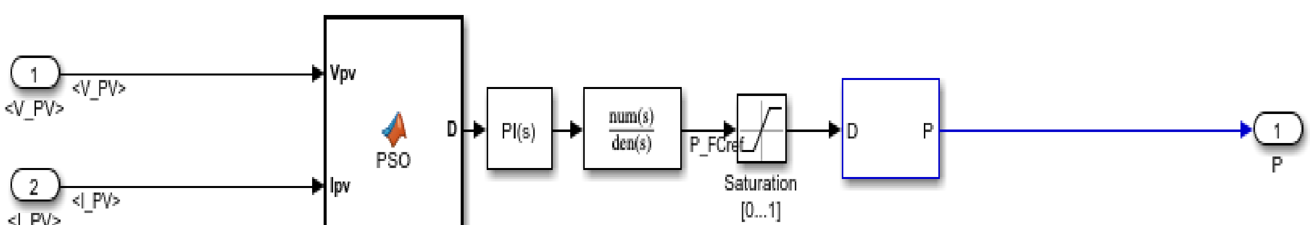

Fig. 5. PV PSO MPPT controller

Fig. 6. Control electrolyzer

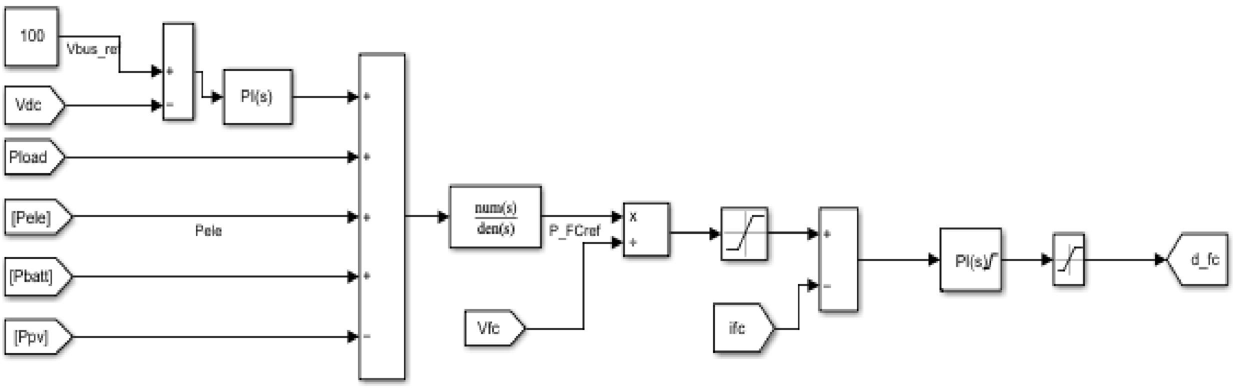

Fig. 7. PEM FC controller

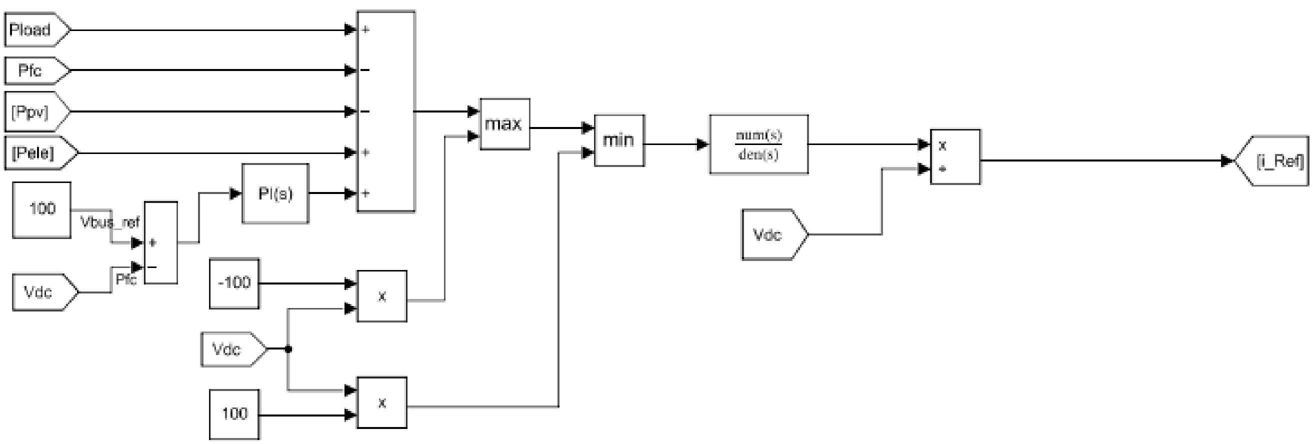

Fig. 8. Battery Charge/Discharge Controller

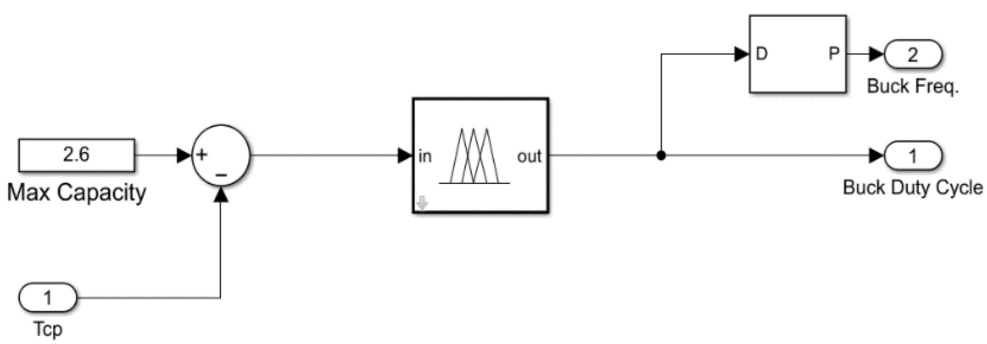

Fig. 9. Hydrogen storage tank pressure controller

2.2. Operation of CEMCA

The photovoltaic (PV) system selected for this study has an 18 kW energy when the radiation and temperature conditions are ideal. The fuel cell (FC) is a power plant that can only produce 6 kW. A PEMFC has been selected for this research because, among the many distinct types of FCs, a PEMFC uses a low functional temperature. Used the alkaline Electrolyzer to produce hydrogen. The surplus power is stored in the hydrogen for keeping in a tank to be utilized in the PEMFC. And a battery bank with a fifty ampere-hour (Ah) capacity may be used with a PEMFC to provide it when necessary.

Additionally, the batteries in the bank make up for the load-following problems and mismatches brought on by the PEMFC. To satisfy load requirements throughout the day and after sunset, a control plan has been designed employing the PV/PEMFC/ELZ/battery hybrid system. The whole process of measuring energy is under the control of the CEMCA. The CEMCA Issues instructions for the power converters attached to the inputs and outputs of the hybrid system's components. These instructions are built around the required measurement.

The power provided by the photovoltaic (PV) system takes priority to meet the load demand over the energy supplied by the proton exchange membrane fuel cell (PEMFC) system or the battery bank.

- The extra power supplied by the PV system will be utilized to run the Electrolyzer for hydrogen production and charge batteries. as shown in Fig. 10a.
- Suppose the total quantity of power generated by the PV system is enough to fulfill the demand. In that case, The extra power supplied by the PV system will be utilized to run the Electrolyzer for hydrogen production. as shown in Fig. 10b.
- If the total power generated by the PV system is enough to fulfill the demand only, as shown in Fig. 10c.
- If the total power generated by the PV system is not enough to fulfill the demand, electricity will be supplied from the PEMFC. as shown in Fig. 10d.
- If the amount of power produced by the PV and PEMFC combination is inadequate to satisfy the load demand, the battery bank will fill the shortage. as shown in Fig. 10e.

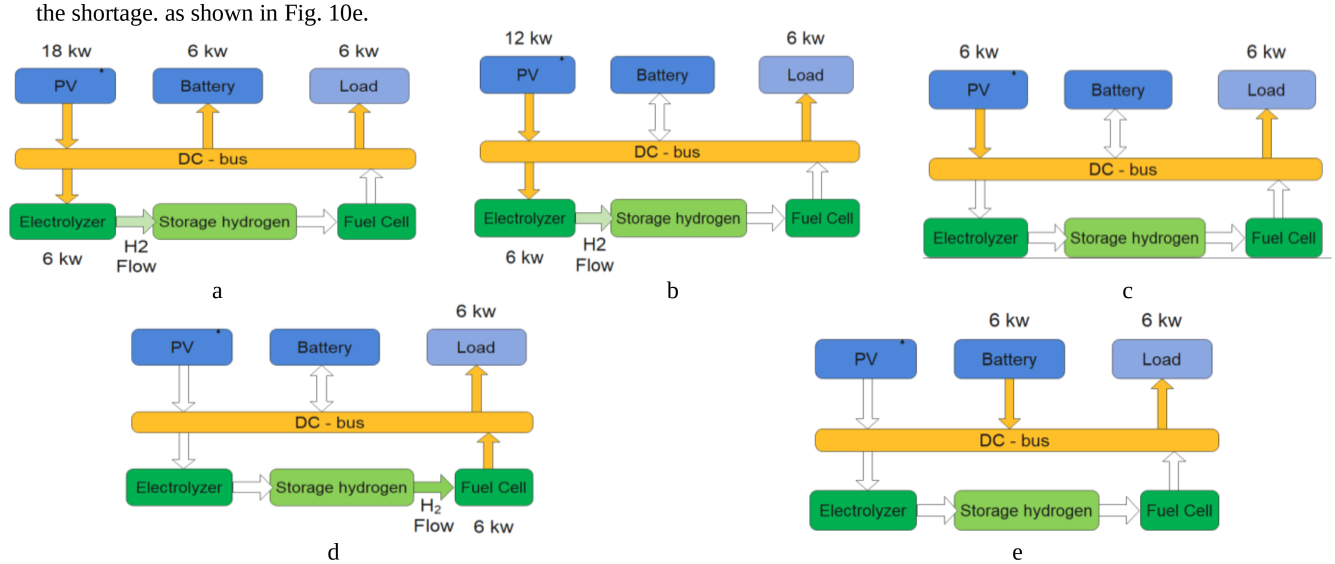

Fig. 10. EM strategy at different load

3. Results and Discussion

The model shown in Fig. 2 was simulated using MATLAB/Simulink. Fig. 3 shows the energy management controller used as the basis for the simulation. Due to the nature of the algorithm, the PV array is relied upon to meet the required capacity for the load, Electrolyzer, and charging of the batteries. The fuel cell system will only activate if the PV array cannot generate any power or if its output exceeds the load demand. If neither the solar array nor the fuel cell provides enough electricity, the battery runs to meet the load requirements. If the battery capacity is exhausted, the system will shut down, as shown in the flowchart in Fig. 11.

Fig. 12. shows the results of the analysis performed on the system after the simulation has been run for a certain duration and under each possible condition. In the first case, the PV would generate enough 18 kW to supply the load, run the Electrolyzer and charge the batteries. While in the second case, the radiation intensity is 240 W/m^2, and the solar panels produce (4.3 kW) and the load (4.7kw). The battery works first because of its quick response, and then the fuel cell works instead of it, which is sufficient to operate the load only, which means that the Electrolyzer does not work and does not charge the battery. Moreover, In the third case, the intensity of solar radiation is zero; that is, there is no electricity generation from the solar panels, so the hydrogen cell operates using stored hydrogen gas to feed the load.

In the fourth case, the radiation intensity of 550 W/m^2 is sufficient for the load and excess to power the analyzer electricity and charge the batteries. In the fifth case, the radiation intensity is zero, so the hydrogen cell works to feed the load. Thus, the process is repeated in several cases, as shown in Table 1. It also demonstrates that the DC bus voltage is within an acceptable range of 100 v, as shown in Fig. 13. Also, Fig. 14 shows the gas flow ratio produced by the electrolyzer.

Table 1 Operation of the system in different cases

cases	Radiation Intensity (W/m^2)	PV (kW)	Fuel cell (kW)	Battery (kW)	Electrolyzer (kW)	Load (kW)
Case1	1000	18	0	3.7 charge	7	6
Case2	240	4.3	(0 - 0.3)	(0.3 - 0) discharge	0	4.7
Case3	0	0	(0 - 2.3)	(2.3 – 0) discharge	0	2.3
Case4	550	9.9	0	1 charge	6	2.3
Case5	0	0	4.9	0.3 discharge	0	4.9
Case6	890	16	0	5 charge	7	3.2
Case7	0	0	(0 – 3.2)	(3.2 - 0) discharge	0	3.2
Case8	190	3.4	(0 – 1.3)	(1.3 – 0) discharge	0	4.5
Case9	600	10.8	0	6 charge	0	4.5

Case10	0	0	(0 – 1.7)	(1.7 – 0) discharge	0	1.6
Case11	410	7.38	0	3.8 charge	0	3.4
Case12	0	0	(0 -1.23)	(1.23 – 0) discharge	0	1.2
Case13	200	3.6	0	2.25 charge	0	1.2
Case14	0	0	4.8	0.3 discharge	0	4.9

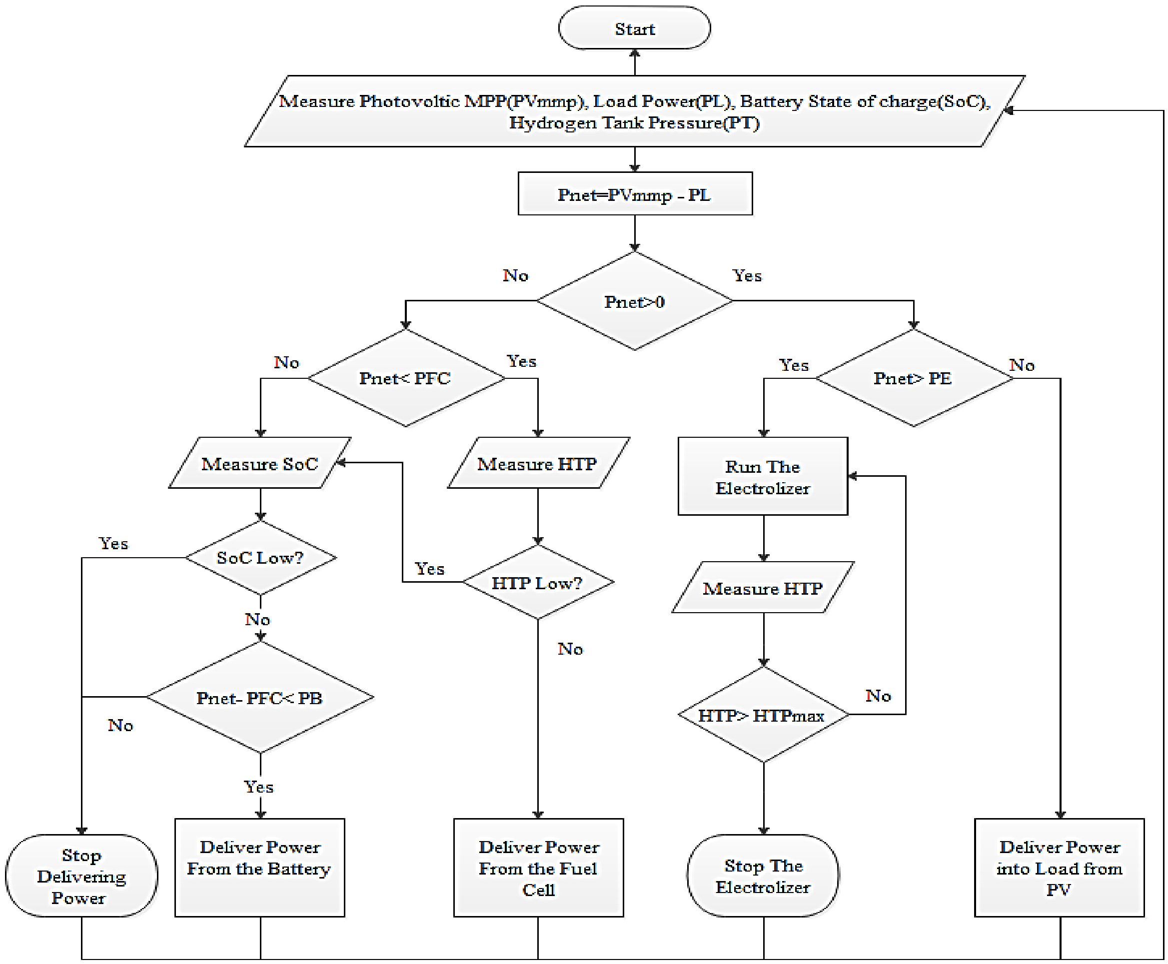

Fig. 11. Energy management flowchart

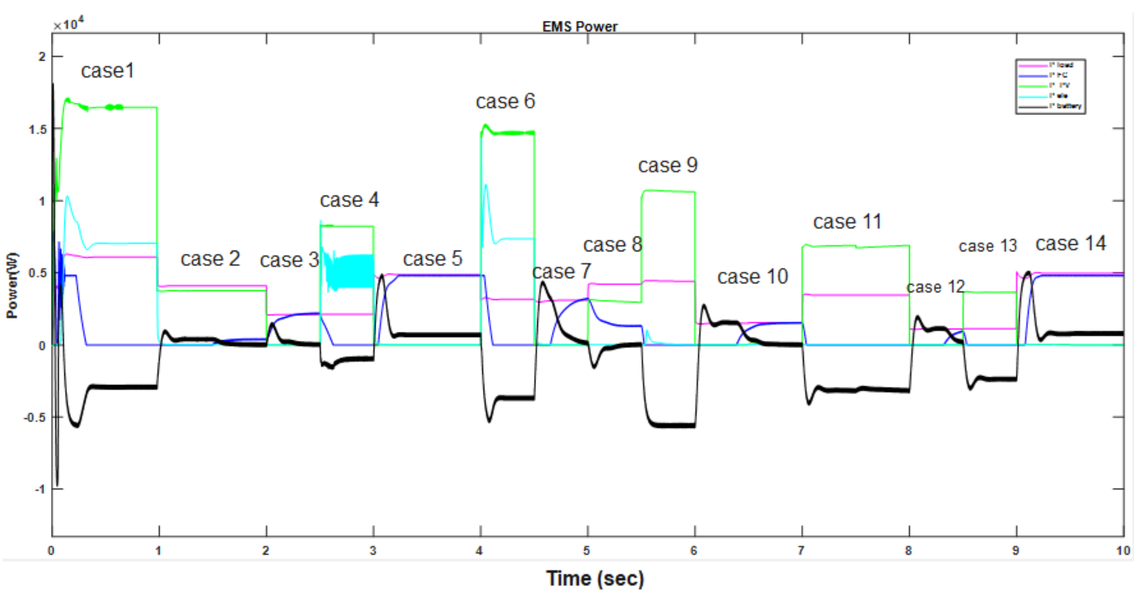

Fig. 12. Power (PV, PEMFC, Electrolyzer, Battery, Load) with Variable radiation and loads

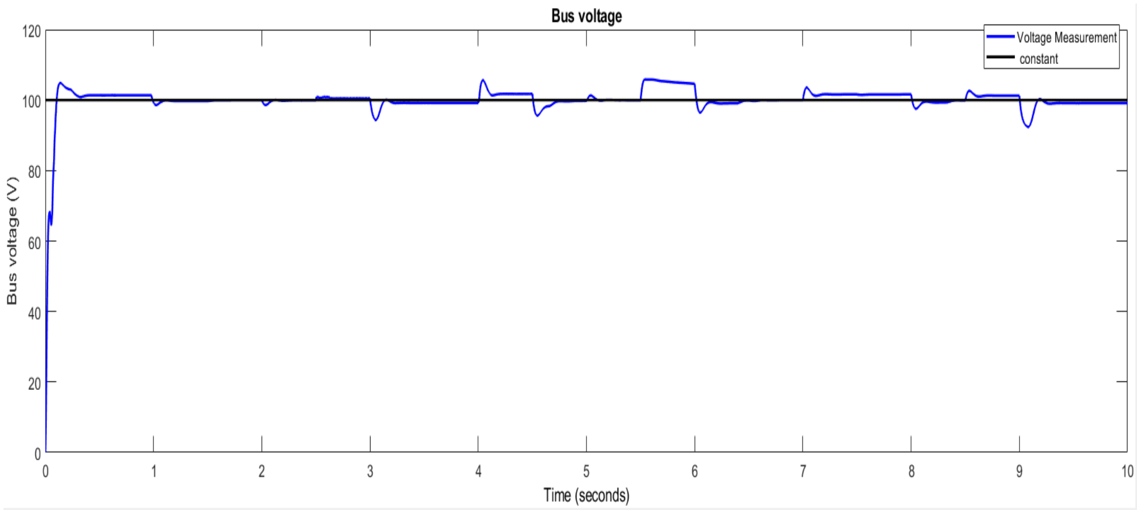

Fig. 13. DC voltage bus

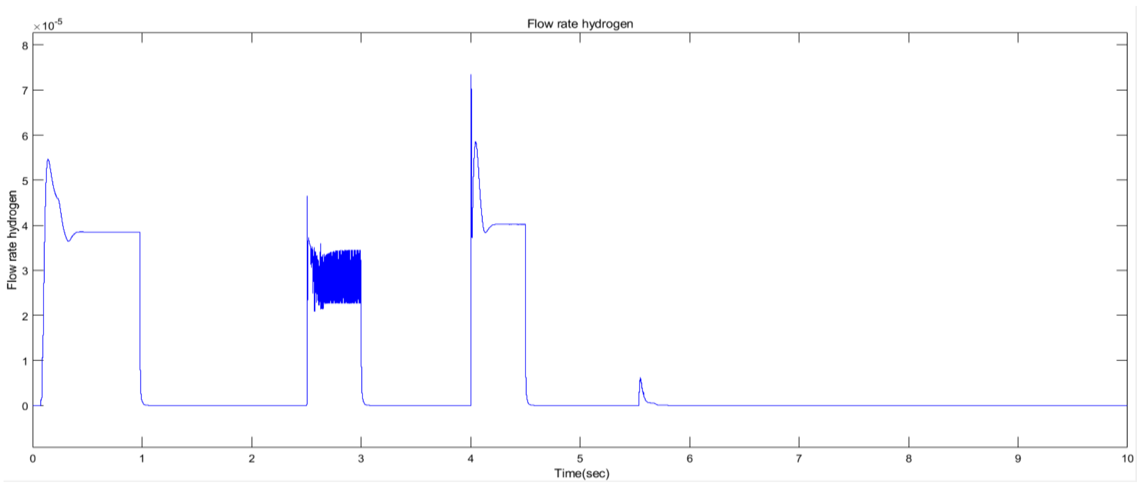

Fig. 14. Hydrogen production (flow rate hydrogen)

4. Conclusion

This article provides an overview of an energy regulation strategy for a hybrid system (HPS) with the production and storage of hydrogen. The system consists of photovoltaic cells (PV), proton exchange membrane fuel cells (PEMFCs), and batteries. With the proposed CEM (flatness, PID, PSO, Nero-fuzzy). The dynamic performance of the proposed system (HPS) has been tested according to the database of recorded photo voltaic radiation and load changes that simulate the actual conditions. MATLAB simulation verifies the effectiveness of the intended system in terms of load tracking, voltage control, power quality, and system stability. An additional power source is no longer needed because PV / PEMFC / ELZ / Battery HPS can provide the power needed for the load for twenty-four hours, and has been the response is high for the changes in the source and load. And achieved good stability in the system.

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