Hydrogen production through the use of solar energy using photovoltaic cells and electrolysis

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Abstract:

The Global warming and other environmental issues have stimulated researchers to explore and implement methods to achieve, this is an unprecedented time in history for green hydrogen with interest being amplified worldwide due to its potential to address the climate crisis as well as energy security and resiliency. Though there are significant challenges, zero and low-carbon hydrogen can be a key part of a comprehensive portfolio of solutions to achieve a sustainable and equitable clean energy future. the clean Energy, the weather-dependent electricity generation from Renewable Energy Sources (RES), such as solar, entails those systems for energy storage are becoming progressively more important. Among the different solutions that are being explored, hydrogen is currently considered as a key technology allowing future long-term and large-scale storage of Renewable Power, The Power-to-Gas concept, based on water electrolysis using electricity coming from renewable sources is the most environmentally clean approach. This article gives an overview of the state-of-the-art green hydrogen production technologies using renewable and sustainable energy resources Hydrogen from water. A proposal In this paper present, This system, which is constituted principally with a photovoltaic array maximum power point tracking (MPPT) algorithms based on Perturb and Observe (P&O), Electrolyzer, compressor, fuel cell, and hydrogen tank the results obtained from system to produce green hydrogen, the case study is carried out to verify the relevance and effectiveness of the proposed management strategy. in MATLAB Simulink Simulation results show that the use of the proposed stand-alone photovoltaic system design with the associated electrical energy and hydrogen management strategy provides a good solution for green energy and hydrogen production with high energy efficiency and low system cost.

***Keywords**: Hydrogen production, Electrolyzer Renewable energy sources (RES), Green Hydrogen, Photovoltaic*

Nomenclature

AC	*alternating current*
DC-DC	*DC/DC Buck Convertor*
DC	*direct current*
IGBT	*Insulated Gate Bipolar Transistors*
MPPT	*Maximum power point tracking*
Mg	*Microgrid*
PV	*Photovoltaic*
PWM	*Pulse Width Modulation*
P&O	*Perturb and Observe*
RES	*Renewable Energy Sources*
RHES	*Renewable Hydrogen Energy System*
RSE	*Renewable and sustainable energy*
TL	*Transmission Lines*
VSR	*Voltage Source Rectifier*
WOA	*Whale Optimization Algorithm*

1. INTRODUCTION

The world is currently looking at hydrogen as an important part of the world's energy transformation system, in order to counter global climate change. Therefore, hydrogen is expected to meet about 24% of the world's energy needs by 2050, equivalent to (700 billion dollars) in sales, with more Billions of end-user products being hydrogen-based Hydrogen is used in a wide variety of applications: ammonia and fertilizer manufacture, poly-silicon production, margarine manufacture, cooling of the power plant and so on[1]. The global energy crisis underscores the need for policy to align energy security needs with climate goals. Hydrogen can contribute to energy security by decreasing dependency on fossil fuels, either by replacing fossil fuels in end-use applications or by shifting fossil-based hydrogen production to renewable hydrogen, The development of an international hydrogen market can additionally add to the diversity of potential energy suppliers, enhancing energy security for energy importing countries in particular. If governments implement ambitious policies to meet their climate pledges, hydrogen could help avoid 14 b cm/yr of natural gas use, 20 Mtce/yr of coal, and 360 kbd of oil use by 2030, equivalent to more than today's fossil fuel supply of Colombia. Heavy industry, heavy-duty road transport, and shipping offer the largest opportunities to deliver fossil fuel and emissions savings. [2]. Due to the rapid spread of global warming issues resulting from the emission of greenhouse gases in the atmosphere of burning oil, gas, and coal, alternative technologies are needed to meet global energy demand, with a focus now on environmentally friendly technologies [11]. Hydrogen cannot be one of the most promising ways to change successful energy when it is produced by Renewable Energy Sources (RES) [12]. Electrical alkaline, proton filter cell (PEMFC), and hydrogen storage. The system consists of PV modules, Proton exchange membrane type hydro Electrolyzer Power control based on bias mode Grid photovoltaic hydrogen scheduling, THE system is proposed to adequately explore fuel energy Proposed in this paper, by which, permeability, to Electric microgrid system, has been achieved. In this paper, we set three parts to the Realization of the power generation system connected to the mini-grid. In The first part, photovoltaic array maximum power point tracking (MPPT) algorithms based on Perturb and Observe (P&O), we introduce the structure of the connected network Generation system as a system overview. In the second part, we narrate alkaline Electrolyzer, and proton exchange in the last part, Governing equations and coordinated control and management strategy The strategy is given as the control design of the system in order to facilitate understanding of the networked system. A case study is carried out to verify the relevance and effectiveness of the proposed management strategy. Simulation results show that the use of the proposed stand-alone photovoltaic system design with the associated electrical energy and hydrogen management strategy provides a good solution for green energy and hydrogen production with high energy efficiency and low system cost.

2. SYSTEM OVERVIEW

The configuration of the stand-alone photovoltaic array energy maximum power point tracking (MPPT) algorithms based on Perturb and Observe (P&O), The Photovoltaic matrix transfer Maximum PV conversion power to DC bus in Real-time by changing PV output with irradiation Density through maximum power point tracking technology. and hydrogen production system The Electrolyzer is used for distillation and separation of alkaline water Consistent Cross Feeding for PV Cells By DC/DC Buck Converter production and demand on the network. When the photovoltaic energy is Higher than the load demand, the Electrolyzer is used as a Backup load to absorb the redundant power of the system. When the photovoltaic energy is less than the load demand, during an apricot day and depends on the temperature and radiation Additional power source to transmit power to the system, they are connected to the common DC bus by DC/DC converter, which eventually transfers power to the external public power grid through DC/AC converter. Transport via Transmission Lines with and connected to An Electric microgrid, also, the system design allows for an Electrolyzer to ensure hydrogen required for H2 users with or without Hydrogen tank support, and storage of excess hydrogen in the hydrogen tank. Used for charger cylinders via connected to the end of the Reciprocating Compressor. The use a software platform is used to verify the feasibility and superiority of hydrogen-based microgrid and the MATLAB/Simulink software a platform is used to check the effectiveness of the system, in shown, Figure 1.

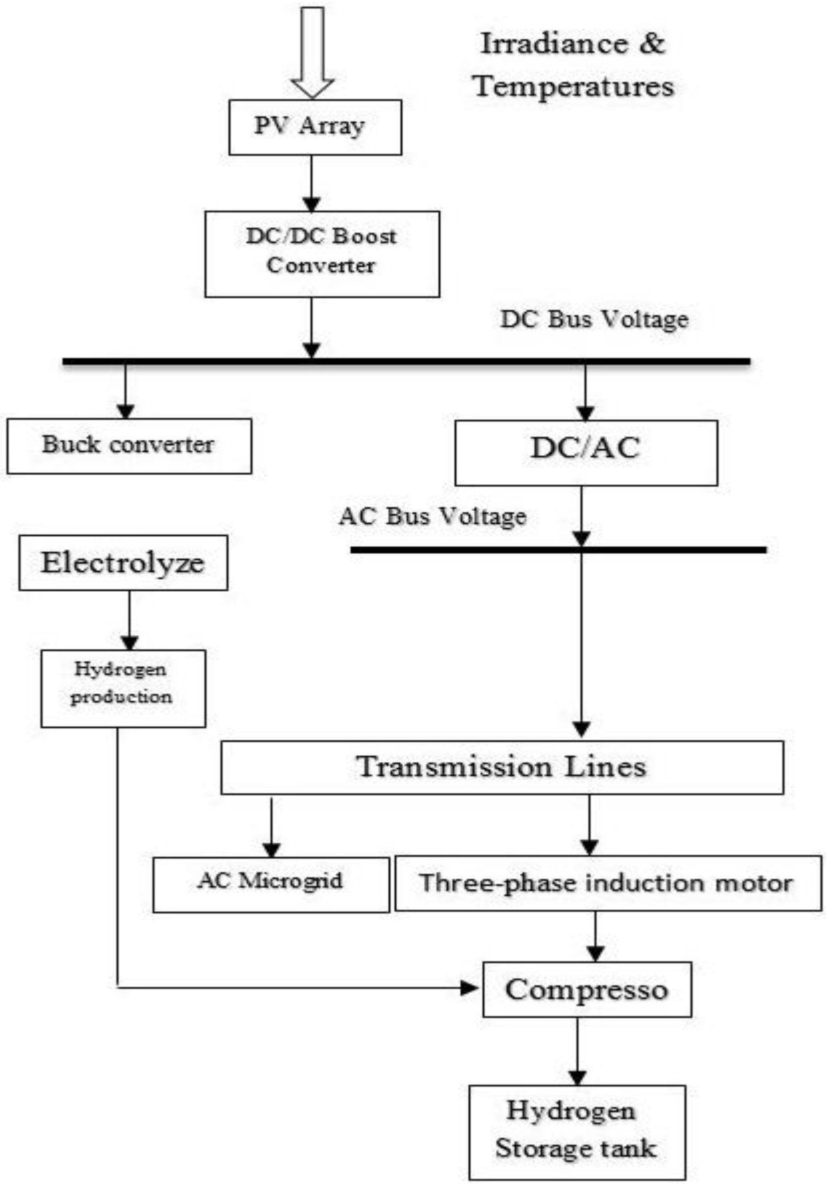

Figure 1. Flow chart for Simulation strategy all system.

3. MODELLING OF THE PHOTOVOLTAIC SYSTEM

Solar cells are made on the P-N junction of semiconductors. It generates electrical energy using photons. It has the ability to attract solar radiation and is to transfer photons to electrons so that this is done with each other [5-6]. The load is connected to the solar cell and charges flow through it by the direct current until the radiation is stopped. [7-8]. as shown, Figure 2. Solar cell modeling is defined by the relationship between the electrical voltages - The photovoltaic system is shipped as mentioned below. [9]. to evaluate system performance, Maximum Power Point Tracking (MPPT), Figure 3. Table 1 shows the characteristics of different Maximum Power Point Tracking (MPPT) techniques as perturb and observe (P&O) algorithm is adopted due its simplicity [10]. Is required to track the MPP and establish the duty cycle of the switch. Accordingly, the operating point is changed which in turn produces more power from the PV array.

$$I = Ipv - Is\ (exp\frac{q(V+RsI)}{Ns\ KTa} - 1) - \frac{V+Rs\ I}{Rp} \quad (1)$$

Where:

I_{pv}: PV current (A), I_s: Saturation current (A), q: Electron charge (1.60217×10^{-19}C), k: Boltzmann constant (1.38065×10^{-23} J/K), a: Diode ideality constant, R_s: Series resistance of cell (Ω), R_p: Parallel resistance of cell (Ω), N_s: No. of cells in series, T: Temperature (K).

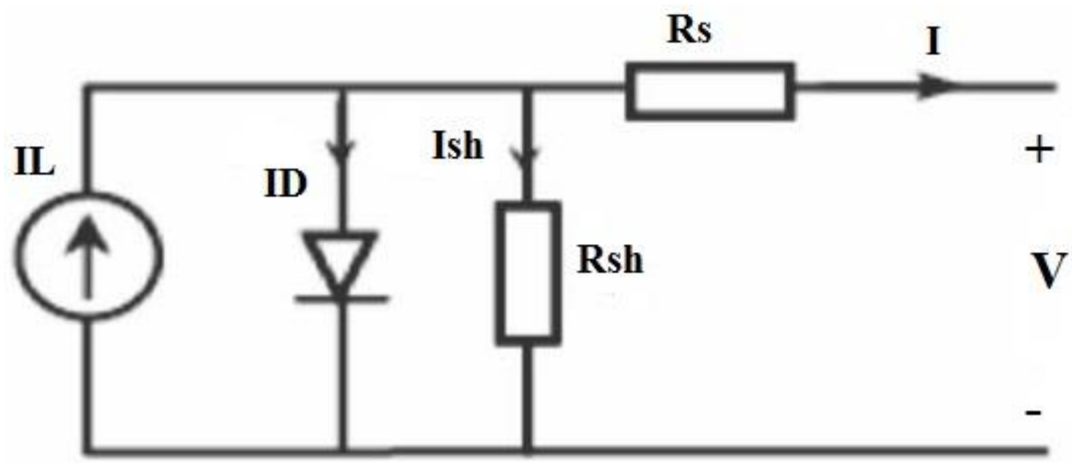

Figure 2. PV Circuit model.

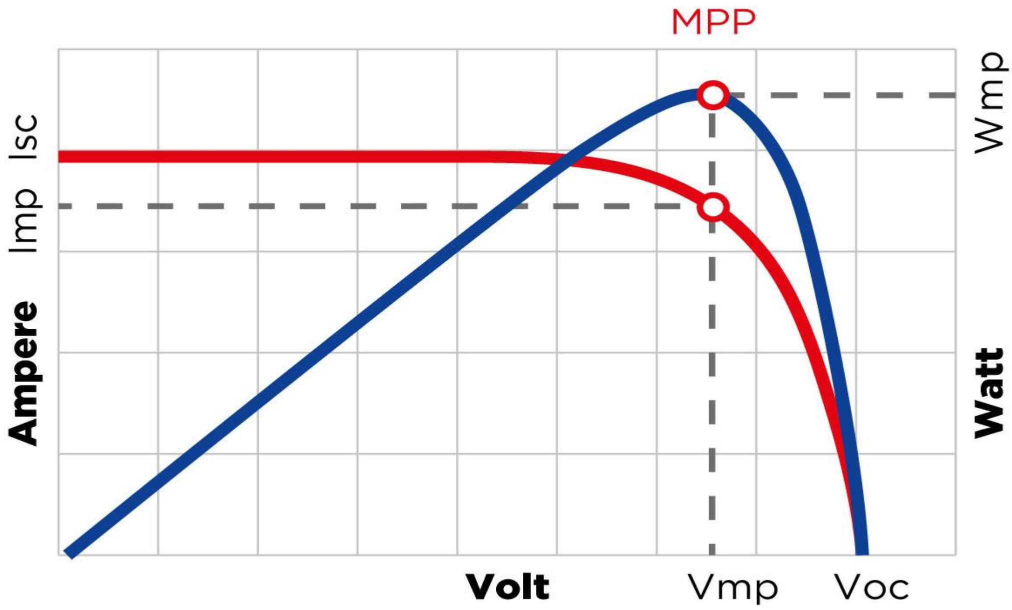

Figure 3. Irradiation and temperature, MPPT (Maximum Power Point Tracking).

Table 1: Characteristics of different MPPT techniques [11].

MPPT Technique	Convergence Speed	Implementation Complexity	Periodic Tuning	Sensed Parameters
Perturb and Observe	Varies	Low	NO	Voltage
Incremental Conductance	Varies	Medium	NO	Voltage - Current
Fractional V_{OC}	Medium	Low	Yes	Voltage
Fractional I_{sc}	Medium	Medium	Yes	Current
Fuzzy logic Control	Fast	High	Yes	Varies
Neural NetWork	Fast	High	Yes	Varies

4. PERTURBATION AND OBSERVATION (P&O) TECHNIQUE

You may notice from the literature and that many researchers have given importance to this direction of MPPT algorithms Based on Perturb and Observe. {P&O} algo Rhythms shown in, Figure 4. The voltage and current released by the photovoltaic cells are measured at first and then the corresponding power (P) is calculated. When the operating voltage of the photovoltaic array is perturbed in a micro direction and {dP/dV > 0} , the disturbance moves the operating point towards the MPP. This technical area continues to defect the PV array voltage in the same direction. If this condition {dP/dV < 0} , where by the operating point is moved away from the MPP and the {P&O} method makes the perturbation direction reversed [12]. The step size depends on the slope of the voltage-voltage curve. Where the slope is obtained using the following Equation, (2).

$$\frac{dp}{dVpv}(n)\frac{P(n)-P(n-1)}{Vpv(n)-Vpv(n-1)} \qquad (2)$$

Where: {dP / dVpv } (n) he is Principal derivative of PV power and voltage, P(n) is the actual power, P(n-1) he is previous energy , vpv (n) is the actual voltage and Vpv (n-1) is the previous voltage. If { V < Vmpp } The Employment Point slides from direction towards the left and when {V>Vmpp } The trigger point moves to the right of the curve shown in, Figure 4. Where {Vmpp } is voltage at maximum power point.

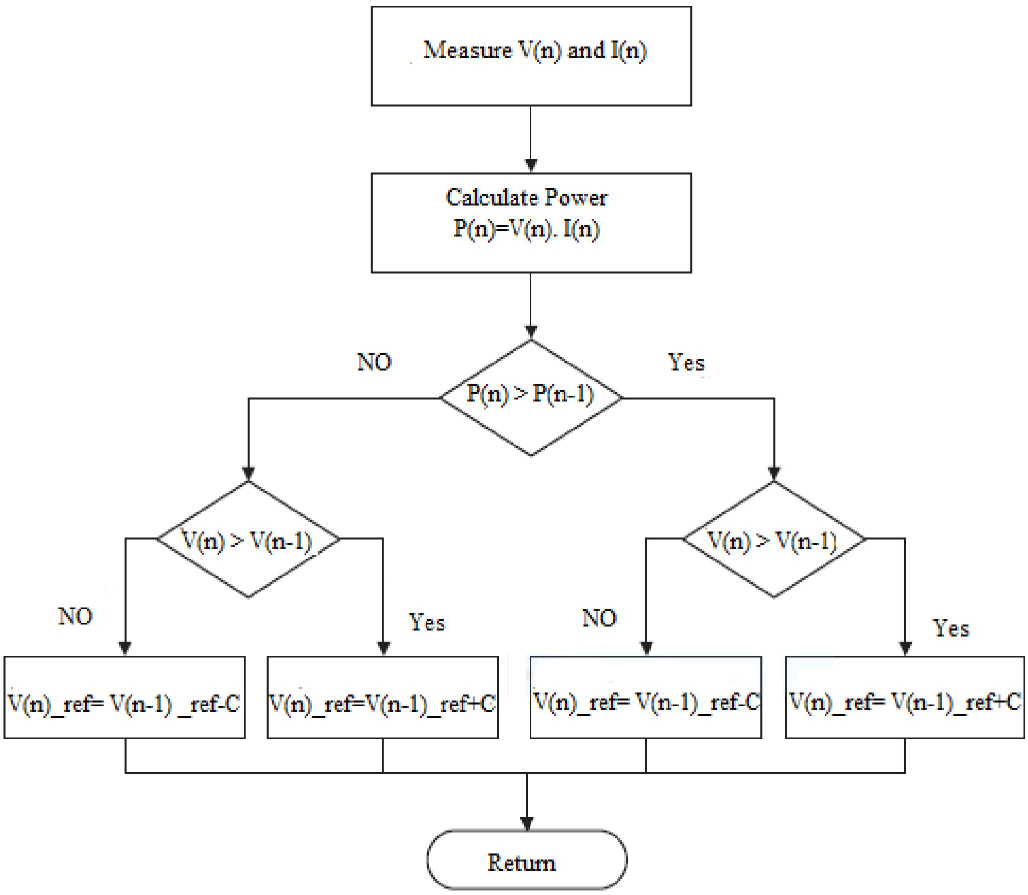

Figure 4. Flow chart for P&O algorithm [13].

5. HYDROGEN PRODUCTION FROM WATER ELECTROLYSIS

Electricity is defined as a device that separates the water ($2H_2O$) into hydrogen ($2H_2$) and oxygen (O_2). electrolysis of water can be classified as a counter-process of hydrogen that is fed in the fuel cell. In terms of electrical chemical reaction that occurs in the fuel cell to generate DC electricity, it turns DC electrical energy into chemical energy stored in hydrogen. the electrical circuit can be represented by electricity as a non-linear DC load sensitive to voltage so that the high voltage applied is the spread of the higher load current and the (H_2)can be created There are two types of electrolysis, Alkaline exchange, and protection (PEM), in shown, Figure 5. It is known that PEM cells are reflected devices for hydrogen systems compared to alkaline electrolysis. They also have many advantages such as smaller dimensions and mass, low energy consumption, and lower operating temperatures, the equivalent circuit is created for Proton Exchange Grass electrolyzer in Matlab/Simulink to run the simulation. [14]. the electrochemical reactions which are taken place in PEM, Near the Anode and Cathode can be illustrated as follows [15].

$$(Cathode) \qquad 2H_2O + 2e^- \rightarrow 2OH^- + H_2 \uparrow \qquad (3)$$

$$(Anode) \qquad 2OH^- \rightarrow H_2O + 2e^- + \tfrac{1}{2} O_2 \uparrow \qquad (4)$$

$$(Total) \qquad 2H_2O \rightarrow H_2 + \tfrac{1}{2} O_2 \uparrow + H_2O \qquad (5)$$

$$\grave{n}_{H2}(\text{mol/sec}) = \frac{\eta_f \,.\, n_c \,.\, i_e}{2f} \qquad (6)$$

Where:

$\grave{n}_{H2}$: Hydrogen production rate . mol s^{-1}

η_f: Faraday's efficiency

n_c: the number of electrolyzer cells in series

i_e: electrolyzer current A

f: Faraday constant (C kmol − 1)

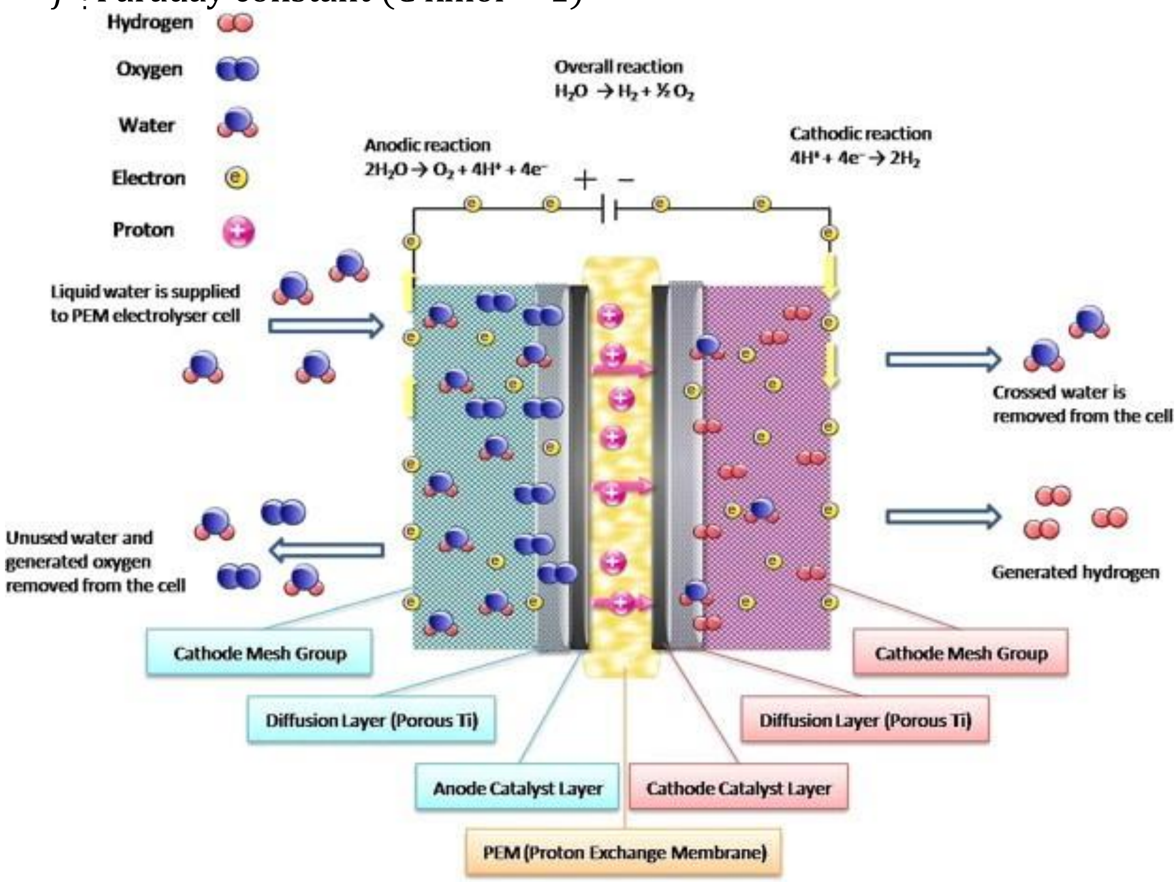

Figure 5. The electrolysis PEM.

6. MODELING OF DC/AC INVERTER

Figure 6 and Figure 7, shows the most often used PV inverter control strategy. This strategy uses double-closed-loop controller and maximum power point tracking (MPPT) controller: the outer voltage loop is used for controlling the active power flow, the MPPT controller is used for choosing the best DC voltage and the inner current loop is aimed for connecting to the grid, while the d-q synchronous frame current controller is the most popular one, as by using the d-q frame current controller, the control variables could become dc values, filtering and controlling can be easier achieved, active and reactive power control also could be decoupled. In this paper, traditional control strategy was used [16].

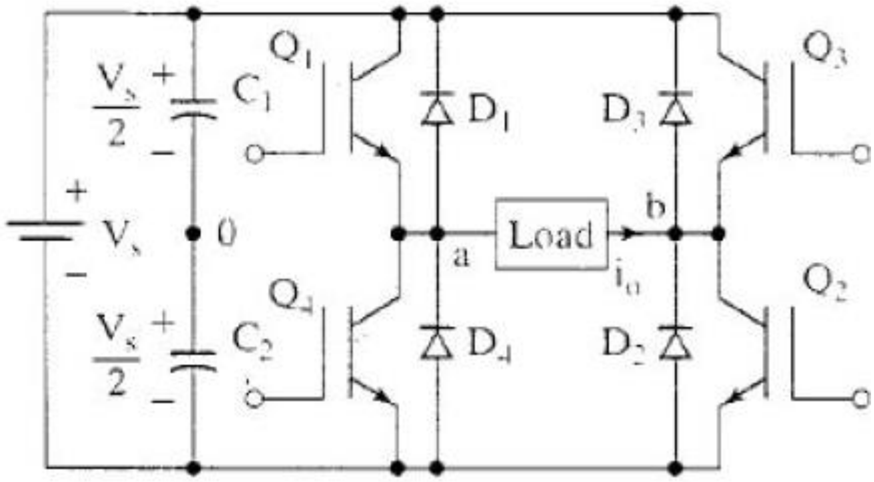

Figure.6 the inverter control

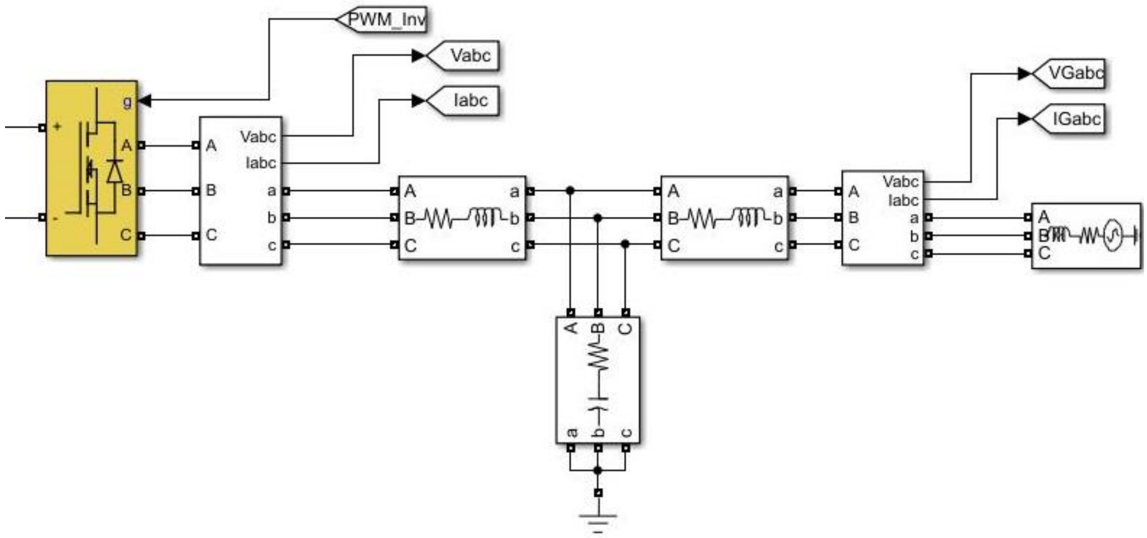

Figure7. Simulink model of the Inverter system (own figure based on Power circuit of three-phase voltage source PWM rectifier).

7. HYDROGEN STORAGE INCLUDING COMPRESSOR

The hydrogen storage is used to store the hydrogen produced by an electrolyzer which can then be used in the fuel cell to regenerate electricity. The hydrogen produced by the electrolyzer needs to be stored to power the fuel cell to ensure electricity supply at times with low incoming PV energy. There are different types of hydrogen storage possibilities, which have different advantages and disadvantages. The fitness of the options depends the intended purpose of hydrogen storage, Figure 8. There are four main hydrogen storage options [17-18].

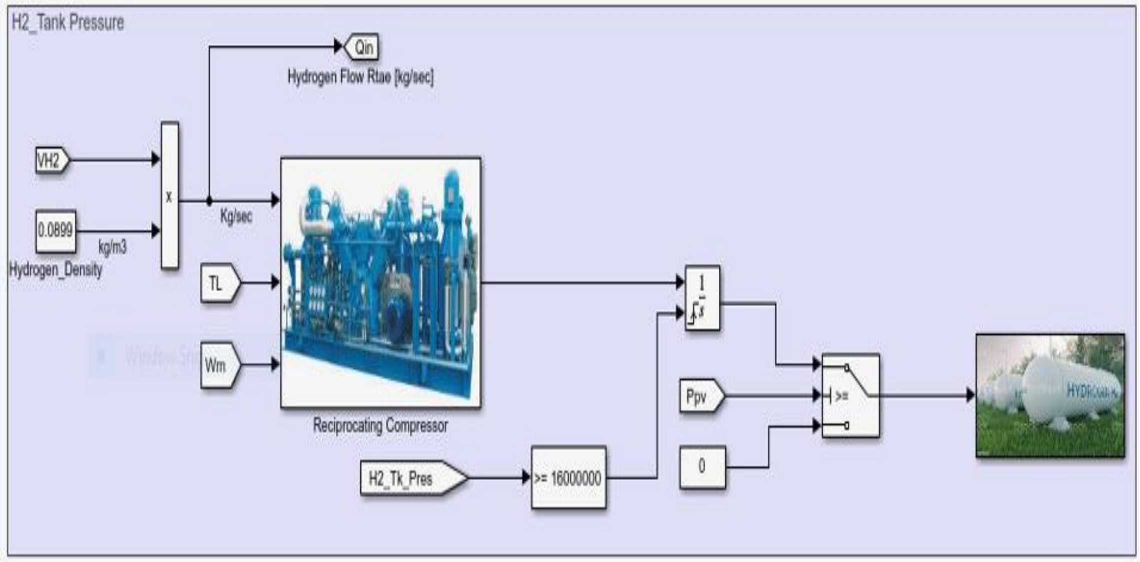

Figure 8. Simulink model, hydrogen storage including a compressor.

8. ANALYTICAL RESULTS

The system shown in, Figure 9. has been simulated using MATLAB/Simulink, The output voltage of the PV arrays is connected directly to a boost converter. The duty cycle of the boost converter thyristor is **adjusted** to identify the maximum power point tracking of the solar PV array. The algorithm utilized in this paper to define the duty cycle ratio at each irradiance and solar temperature value is Perturb and Observe (P & O). The algorithm checks continuously the PV array to extract the maximum power. The irradiance (w/m2), output voltage of the PV array P_ PV (v) and the output current of the PV I_PV (A) are depicted in, Figure 9.

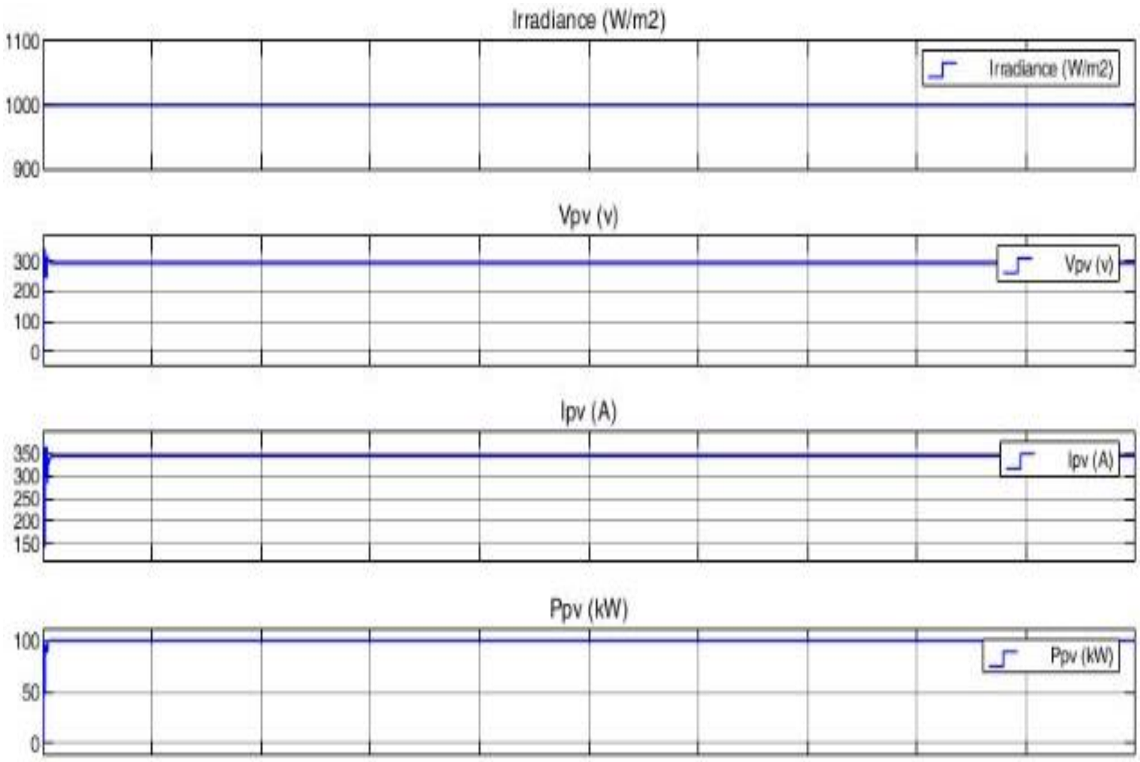

Figure 9. Indicates the PV array.

The DC bus voltage supplies the necessary power to the electrolyzer. the electrolyzer is connected to the DC bus voltage via two conditional circuit breakers and buck converter with a PI controller, a pipe to a compressor which discharge it to a hydrogen storage tank for further utilization are depicted in, Figure 10.

Figure. 10. Indicates the electrolyzer.

The DC bus voltage is connected to an AC microgrid via three-phase bridge inverter and a transmission line. The function of the inverter is to convert the DC power into AC power three-phase power in dq-rotating reference frame. a transmission line is adopted to transfer the power from the inverter output to the AC microgrid The AC microgrid is 380V three-phase power that is employed to supply users. the AC microgrid currents, voltages in the shows Figure 11.

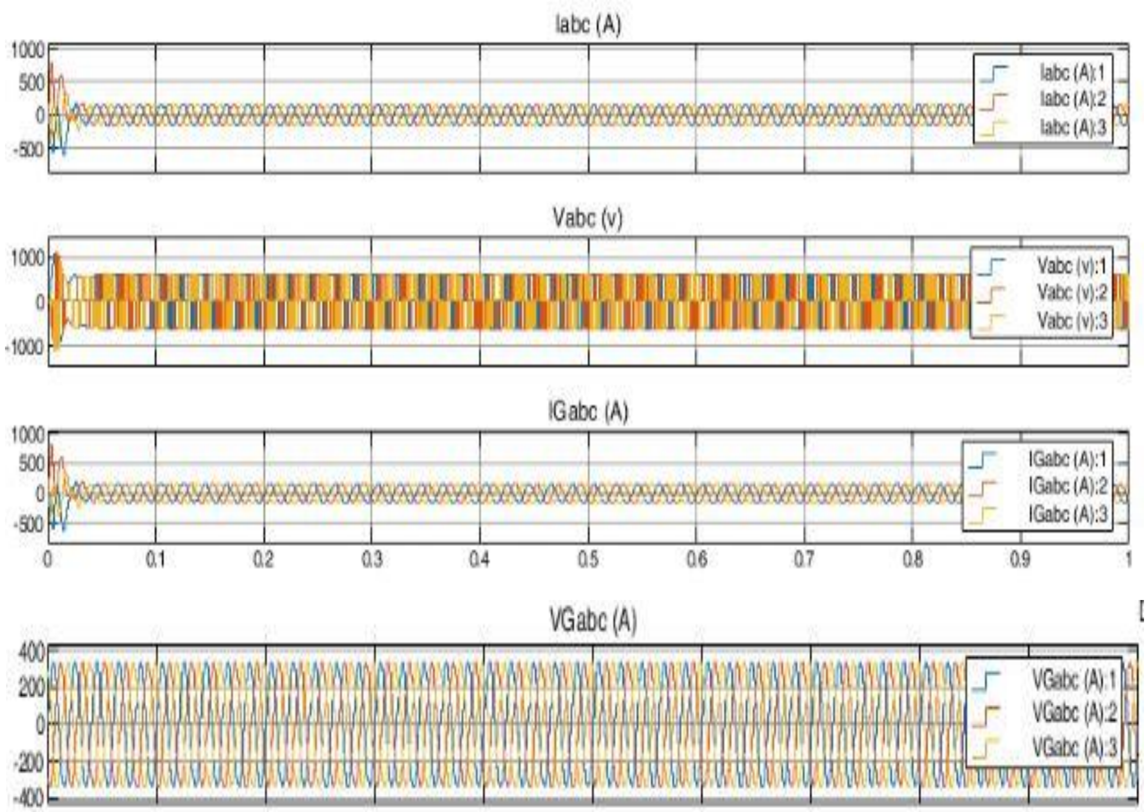

Figure. 11. The three-phase currents.

9. FUTURE ASPECTS

Hydrogen offers significant potential as a future dream fuel, with numerous social, economic, and ecological impacts. It offers the long-term potential to diminish reliance on foreign oil while also lowering carbon and criterion emissions from mobility [19]. Recent research was undertaken on the generation of hydrogen using photovoltaic and electrolysis PEM Initiatives are being undertaken to investigate new cost-effective hydrogen storage and transportation techniques [20]. The significant technological challenges must now be overcome in order to move away from a carbon-based energy system and toward a hydrogen-based market [21]. The cost of producing and delivering hydrogen must be cut significantly, and that is very crucial. It is necessary to create new generations of stationary and mobile hydrogen storage solutions [22]. Finally, it is necessary to lower the price of fuel cell as well as other hydrogen-based systems. The key marketplaces for hydrogen in the future are primarily influenced by four factors, such as the price of hydrogen in the future, the rate at which different technologies using hydrogen are developed, potential long-term limitations on greenhouse emissions, and the price of competing energy systems [23]. The primary objective of future studies will be to create cost-effective microgrid systems with hydrogen generation and CO2 data acquisition services by developing and applying novel evolutionary algorithms and microgrid infrastructure components that integrate sophisticated techniques and effective energy management tools [24].

10. CONCLUSION

In this work, attention was focused on the study of the energy management strategies for an isolated micro-grid with hydrogen production and storage under construction. From real meteorological data, This paper aimed to conduct the life cycle assessment, this study provides a solution to the greenhouse gas emissions and the energy insecurity clearly noticed through the quick depletion of the natural fossil fuel. Clean and sustainable energy and hydrogen production to satisfy the world needs are very possible using the proposed stand-alone photovoltaic energy and hydrogen production system. The system is designed to meet at the same time the load with sufficient clean electrical energy, store the energy surplus in the accumulator and produce hydrogen via water Electrolyzer.

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