16th International Conference on Clean Energy (ICCE-2018)
9-11 May 2018, Famagusta, N. Cyprus

DESIGN OF A PHOTOVOLTAIC POWER AND HYDROGEN BASED STAND-ALONE HYBRID RENEWABLE ENERGY SYSTEM ON A MOBILE PLATFORM

Akın USLU, Ali PASHAEI, Nabeel ALTANNEH, M. Timur AYDEMİR
Gazi University, Faculty of Engineering, Department of Electrical and Electronic Engineering & Clean Energy
Corresponding author: Mehmet Timur AYDEMİR, e-mail: aydemirmt@gazi.edu.tr

REFERENCE NO

PVLT-04

ABSTRACT

Renewable energy sources can be utilized together to supply the needs of houses. Gazi University Clean Energy Research and Application Center (TEMENAR) has built a mobile platform to study and promote renewable energy systems. The platform includes PV panels and a hydrogen fuel cell. In its current form these units operate independently. The purpose of this paper is to design a controller and DC-DC converters to efficiently operate the system.

Keywords:

Renewable Energy Systems, Photovoltaic Power, Fuel Cell, Hybrid Renewable Energy Sources, Electrolysis

1. INTRODUCTION

Renewable energy sources can be utilized to power houses in remote areas where the ac grid is not available. Depending on the available sources a hybrid system can be designed to supply the loads. In this case a main controller is necessary to determine which source will be utilized to supply the load, to charge the battery or to generate hydrogen, if there is a fuel cell stack in the system.

Solar energy is abundant in many areas of Turkey and a PV system should be at the center of any such system. As the voltage of the PV panels vary depending on the drawn current they should be operated at the maximum power point of their i-v characteristics. This is achieved by employing a proper Maximum Power Tracking Algorithm (MPPT) in the control of the dc-dc converters which are connected at the output of PV panels. MPPT algorithm continuously track output voltage of the dc-dc converter and changes the duty cycle of the pulse width modulation signal to follow the reference voltage. It is implemented with voltage feedback PI control technique that provides constant output voltage.

Many algorithms have been proposed such as Incremental Conductance [1], Perturb and Observe (P&O) [2], Constant Voltage and Current [3], Hill Climbing algorithms. P&O algorithm is widely used and known for its simple implementation.

Fuel cells are electrochemical devices that convert the energy of the chemical reaction to electrical energy. In this paper PEMFC (Proton exchange membrane fuel cell) was used because it has high power density, low operating temperature, zero or low emission, low weight and volume. Like in solar panels, it has a unique i-v curve which represents maximum power point (MPP) and it is necessary to force the PEMFC in operating condition which matches MPP with the help of DC-DC converters [4,5,6].

In this paper a hybrid system consisting of PV panels and a fuel cell is introduced. The system was designed and built by the Clean Energy Research and Application Center of Gazi University. Its units were originally designed to operate independently. The purpose of this paper is to suggest an integration scheme, a main controller and dc-dc converters.

This paper is organized as follows: Section 2 discusses the structure of the proposed system and the design of the controller. In Section 3 design of the converters and simulation results are presented.

2. SYSTEM STRUCTURE

The Clean Energy Van (CEV) has PV panels, a fuel cell and electrolysis devices. These units can be integrated together in a system shown in Fig. 1. The energy received from the PV panels can charge a battery with an MPPT algorithm. The battery is used to supply the ac loads through an inverter. If the solar energy is excessive, it can be used to generate hydrogen through electrolysis. An efficient dc-dc converter can be utilized for this purpose. If the battery and PV panels are not able to supply the load, the stored hydrogen can be used to generate electricity through the fuel cell. The generated voltage is applied to the common dc bus through another dc-dc converter.

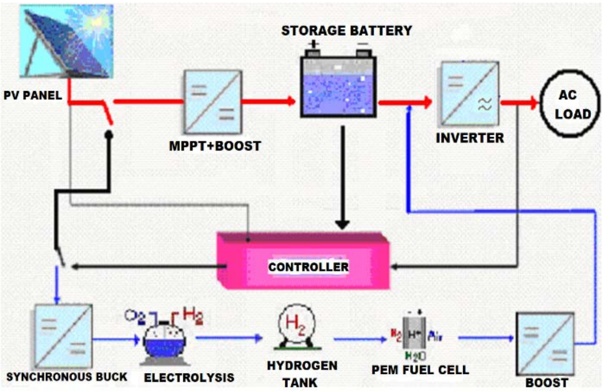

Fig. 1. Schematic diagram of the system

The CEV has 24 PV panels, 85 Wp each placed at the top and a 1.2 kW fuel cell placed inside. The energy received from the panels is used to charge batteries. The battery stack is designed for 48 V and it is allowed to go up to 52-53 V. There is no dc-dc converter currently in between the panels and the batteries. The proposed structure includes a dc-dc boost converter running with Perturb-and-Observe (P&O) MPPT algorithm. The inverter which is fed from the battery generates the ac voltage required by the ac loads.

When the solar energy is enough to meet the demand by the load fuel cell is kept in stand-by mode. If there is more energy than needed the excess energy is used to charge the battery. If the batter is also full, the excess energy can be used to generate hydrogen through the electrolysis process. Generated energy can be stored in special metal tanks. If the solar energy is not enough or not available at all, the battery supplies the load. If the battery voltage drops below a certain level the fuel cell kicks in to generate the required power.

A controller is needed to perform all these steps. In this section the function and operation of this controller is discussed.

Electrolysis is performed when the battery voltage reaches a certain level. In this application the voltage level has been chosen as 52 V. The electrolysis process which is shown in Fig. 2 can continue until the battery voltage drops to 50 V. This hysteresis nature of the controller makes sure that the electrolysis process does not continuously switch between two states.

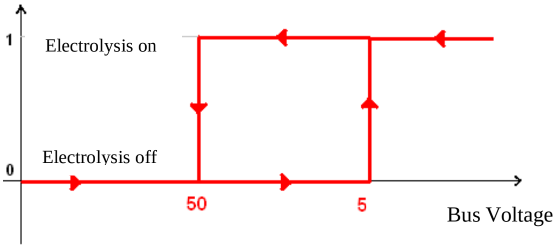

Fig. 2. Hysteresis control structure for electrolysis

A similar hysteresis controller can be used for the fuel cell stack. When the load is supplied by the battery alone, its voltage drops sharply. When the voltage level drops to 49 V fuel cell kicks in and takes over the load. Depending on the load and the available solar energy, battery level may stay constant at 49 V or may increase slowly. If the voltage level increases and reaches to 51 V then the fuel cell is disabled and the load is taken over by the battery. The hysteresis control is shown in Fig. 3.

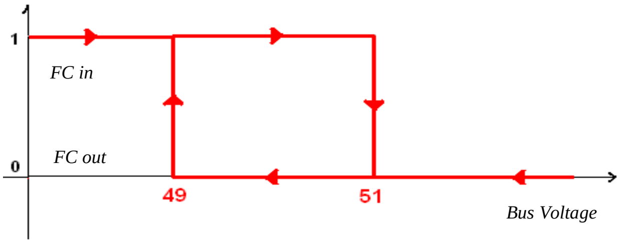

Fig. 3. Hysteresis control structure for fuel cell stack

The performance of the controller has been tested with a model built in MATLAB Simulink for various operation modes. Three of these modes are given here to show the principles.

Mode 1: In this mode available solar power is more than the load demand and therefore the battery voltage also rises. When the voltage reaches to 52 V, the electrolysis process starts. In the simulation, PV power is fixed to 1000 W while the load is 500 W. The bus voltage initial value was kept slightly below 52 V. The battery voltage reaches 52 V at 132 ms as shown in Fig. 4 and electrolysis process is started. The simple electrolysis model implemented in MATLAB shows that 25 W is consumed at this stage. As the difference between the load and available power is big, battery voltage keeps increasing. More hydrogen production or less power difference will change these parameters.

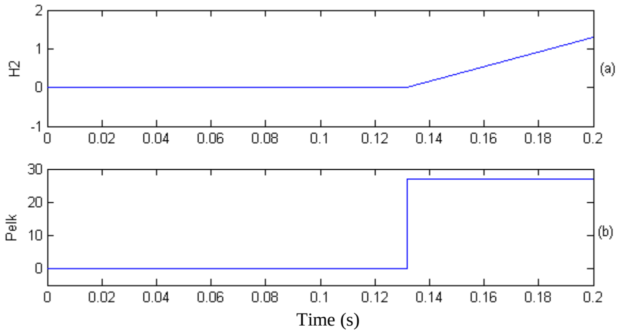

Fig. 4. Hydrogen production and electrolysis power consumption in Mode 1.

Fig. 5 shows bus voltage variation in this mode. Fuel cell output current is zero since there is no energy drawn from it. The small oscillations are due to the filter across the output.

Mode 2: In this mode the solar energy is used to generate hydrogen, and the load is supplied by the battery. As a result the battery voltage slowly drops. When the voltage drops to 50 V the electrolysis process is stopped. In the simulation load power is kept at 4000 W and the initial value of the battery voltage is slightly over 50 V. The battery voltage drops to 50 V as seen in Fig. 6.

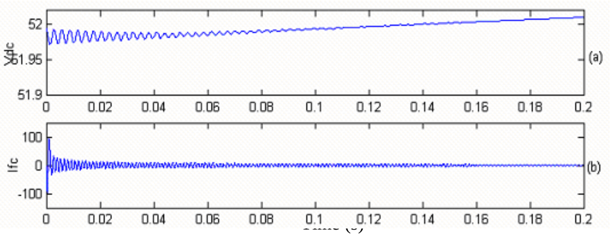

Fig. 5. Bus voltage and fuel cell output current in Mode 1.

When the battery voltage reaches down to 50 V, the electrolysis is stopped and hydrogen production ends (Fig. 7).

Mode 3: In this mode the load is supplied mainly by the battery. When the battery voltage drops down to 49 V the fuel cell kicks in.

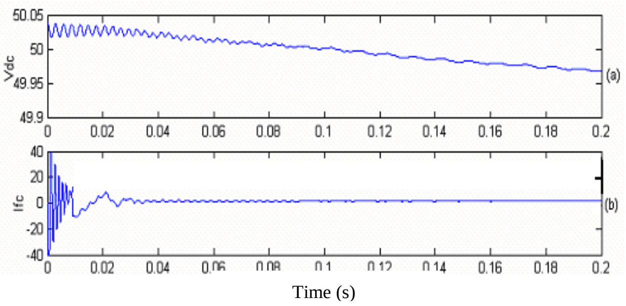

Fig. 6. Bus voltage and fuel cell output current in Mode 2.

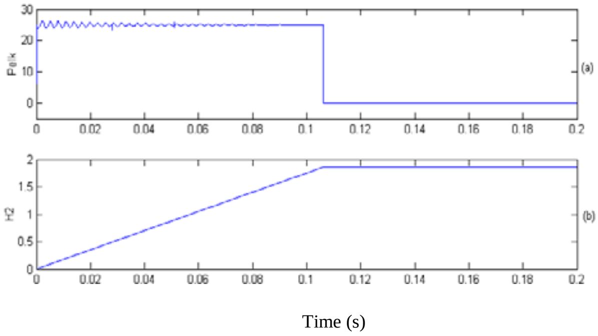

Fig. 7. Hydrogen production and electrolysis power consumption in Mode 1.

In the simulations load power is fixed to 4000 W and initial value of the battery is set to 49.1 V. When the fuel cell starts generating electricity its controller operates it at constant current mode at the rated current. The principal waveforms are shown in Fig. 8.

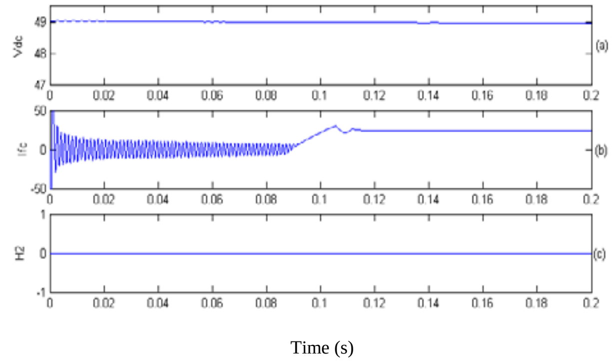

Fig. 8. Bus voltage, fuel cell current and hydrogen production in Mode 3.

Fig. 9 shows the fuel cell current, voltage and power in this mode. As the current increases towards the rated current value, the voltage drops from open circuit voltage towards the rated value and the power increases towards the rated current.

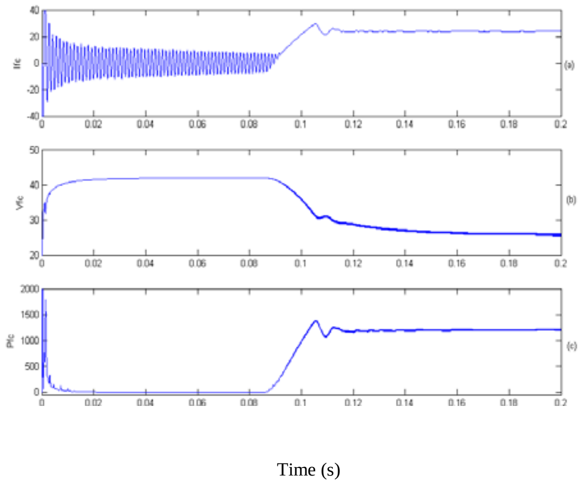

Fig. 9. Fuel cell current, voltage and power in Mode 3.

3. POWER STAGE AND DC-DC CONVERTERS

The boost converter at the output of the PV panels increases the voltage from the MPP voltage (around 17 V) to the bus voltage which is 48 V by using MPPT algorithm. The closed loop controller structure is shown in Fig. 10.

Design parameters of the boost converter are given in Table 2.

Table 1. Main Parameters of the PV system

Parameter	Value
Number of PV cells	36
Maximum Power (Pmax)	85W
MPP Voltage (Vpm)	17.1
MPP Current (Ipm)	4.97
Open Circuit Voltage (Voc)	21.1
Short Circuit Current (Isc)	3.8

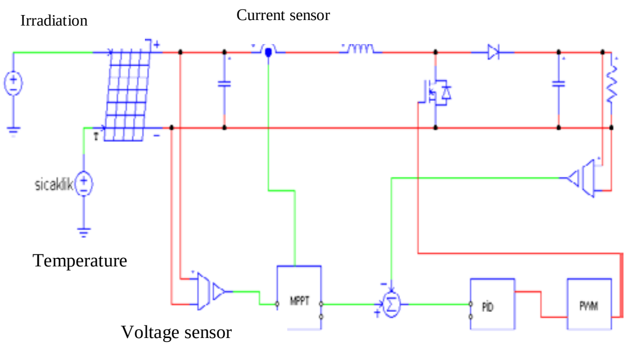

Fig. 10. The boost converter operating with MPPT algorithm

Table 2. Design parameters for the boost converter

Input Voltage Range	12-20V
Rated Output Voltage	48 V
Switching Frequency	20 kHz
Power	1200 W
Current Ripple	% 15
Voltage Ripple	% 1

The design process yields an inductance value of 40 µH and a capacitance value of 2 mF. This is for simulation purposes and there is actually no need to have this much capacitance as the output is connected to a battery.

A PID controller has been designed for the control and the transfer function of the controller has been obtained as

$$G_c(s) = \frac{1.4\,10^{-6}\,s^2 + 4.9\,10^{-4}\,s + 4.4}{s} \qquad (1)$$

The open loop Bode diagrams for the controllers are given in Fig. 11. Fig. 12 shows the performance of the controller in different conditions.

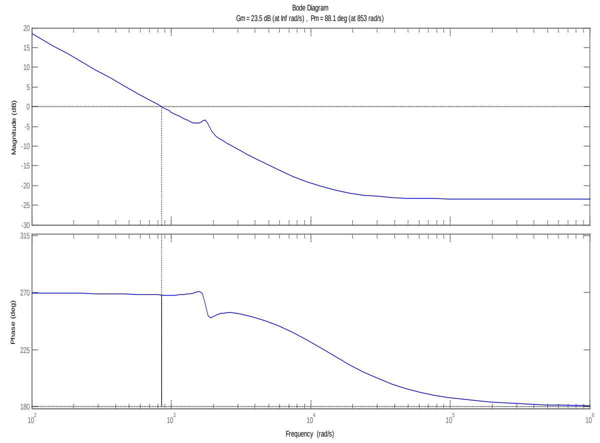

Fig. 11. Open loop response of the PID controller

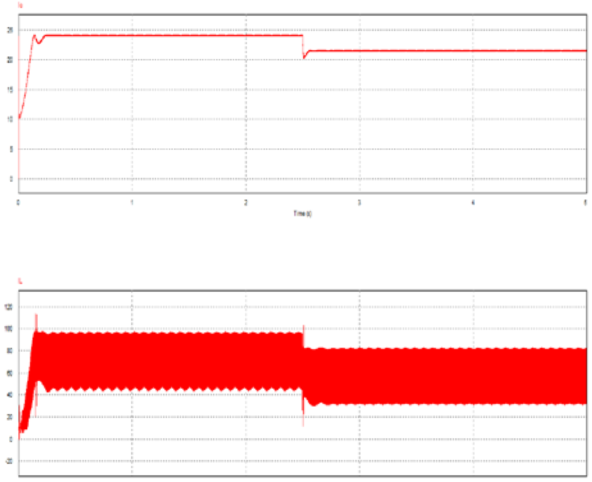

Fig. 12. Output voltage (top) and inductor current (bottom) response to variation of radiation from 1000 W/m^2 to 800 W/m^2 at 25 ℃.

A synchronous buck converter has been designed for the electrolysis system. Electrolysis voltage is low and freewheeling voltage of the standard buck converters reduce the efficiency enormously. Therefore, a synchronous MOSFET use is the natural choice as shown in Fig. 13.

The design parameters of the converter are given in Table 3.

Calculations yield a filter inductance of 30 μH and capacitance of 147 μF. Open loop transfer function of the controller is obtained as

$$T_1(s) = \frac{17}{4.5*10^{-9}s^2+12*10^{-3}s+4.5*10^{-3}} \qquad (2)$$

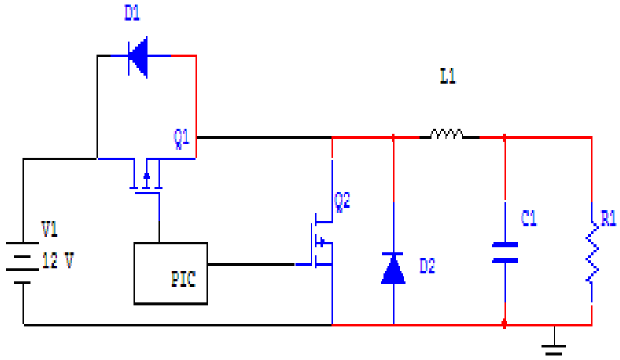

Fig. 13. Synchronous buck converter for electrolysis

Table 3. Design parameters for the synchronous converter

Input voltage	12-20V
Output voltage	3-4V
Switching frequency	20 kHz
Rated power	200W
Current ripple	%15
Voltage ripple	%10

Open loop bode plots are given in Fig. 14.

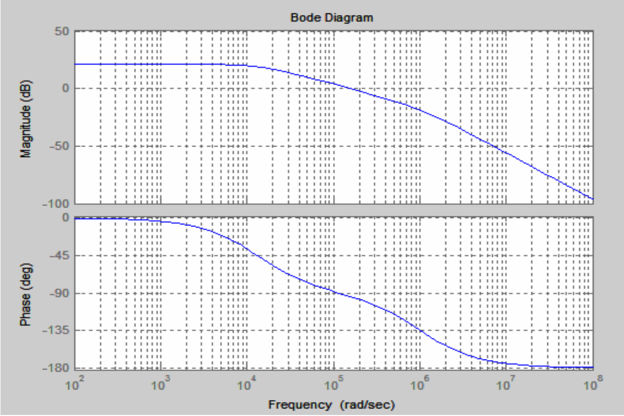

Fig. 14. Open loop bode plots for the converter

A compensator with the transfer function given in (3) has been designed for the controller and the closed loop bode plots of Fig. 15 are obtained.

$$T_c(s) = \frac{s+23*10^3}{3.7*10^{-5}s+(s+43{,}4*10^3)} \qquad (3)$$

Fig. 16 shows the response of the converter to a disturbance.

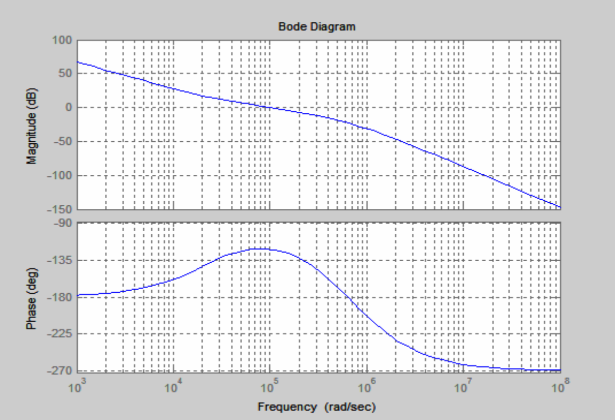

Fig. 15. Closed loop bode plots for the electrolysis process

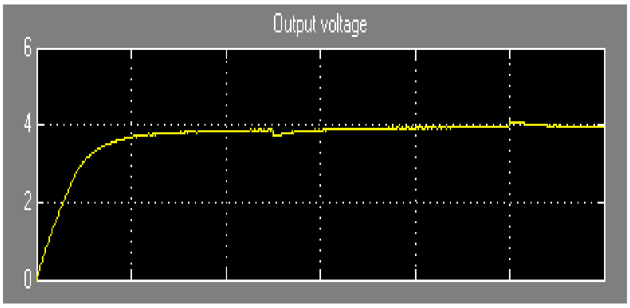

Fig. 16. Response of the converter to disturbances

The third converter needed for the operation of the system is for the fuel cell output. When the fuel cell runs it generates a voltage that varies between 26 – 44 V. This voltage is step up to 48 V which is the dc bus voltage. The parameters of the boost converter for this operation are given in Table 4.

Table 4. Converter parameters for the fuel cell

P_{max}	Maximum output power	1200 W
f_{sw}	Switching frequency	60 kHz
V_s	Rated input voltage	26 V
V_s^{max}	Maximum input voltage	44 V
V_o	Rated output voltage	48 V
I_o	Output current	20 A
V_r/V_o	Output voltage ripple	< %1
ΔI_s	Current ripple	< 5A

Fig. 17 shows the Simulink model used in the simulations.

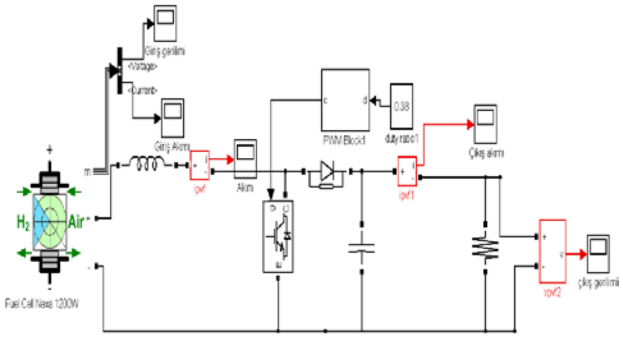

Fig. 17. Simulink model for the FC and converter

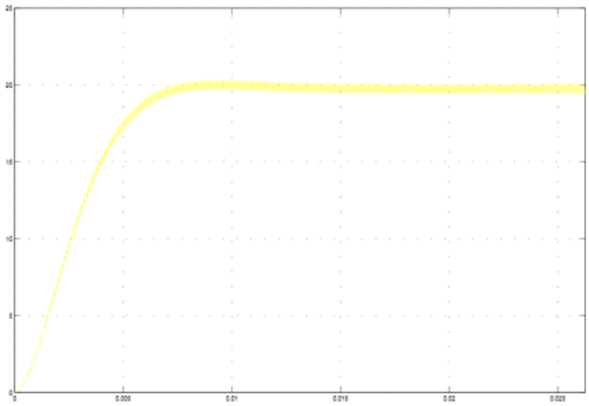

Fig. 18. FC output current response

4. CONCLUSION

Hybrid renewable energy systems present a solution to the power requirements of remote houses. In this paper a solar – hydrogen hybrid system was designed for a mobile platform designed by the Clean Energy Research and Application Center of Gazi University. A controller is proposed to manage the source allocation and power converters have been designed for PV panels, electrolysis unit and fuel cell. More work needs to be done to efficiently use the system.

5. ACKNOWLEDGEMENT

This work has been conducted under the project 06/2012-16 which is supported by Gazi University Scientific Research Projects (BAP) program. Authors wish to thank Gazi University BAP for this support.

References

[1] K. Hardo, and G. Zhao, "Controlled power interface between solar cells and ac source "IEEE Trans. On Power Electronics, vol.8, pp. 654-662, October 1993.

[2] [2] Dezso Sera, Remus Teodorescu, Jochen Hantschel, and Michael Knoll; "Optimized Maximum Power Point Tracker for Fast-Changing Environmental Conditions" IEEE Tran. On Industrial Electronics, vol. 55, No. 7, July 2008.

[3] H.D. Maheshappa, J.Nagaraju, and M.V. Krishna Murthy " An improved maximum power point tracker using step-up converter with current locked loop" Renewable Energy Conversion and Management, vol.13 , No.2, pp. 195-201, 1998

[4] Wu and R. W. G. Bucknall, "Downsizing fuel cell capacity in a hybrid hydrogen vehicle by regenerative energy capture with super capacitor," 2014 49th International Universities Power Engineering Conference (UPEC), Cluj-Napoca, 2014, pp. 1-6Universities Power Engineering Conference (UPEC), Cluj-Napoca, 2014, pp. 1-6.

[5] D. Xu, W. Zhang, H. Li and M. Chen, "A fuel cell uninterruptible power supply (FC-UPS) system," 2013 5th International Conference on Power Electronics Systems and Applications (PESA), Hong Kong, 2013, pp. 1-4. doi: 10.1109/PESA.2013.6828237

[6] Altanneh N., Battery Charge System Design and Implementation for a Small Electric Car Using PV Panels and Full Cell, (Master Thesis), Gazi University, June 2012.