# DC – DC BOOST CONVERTER FOR HYBRID PV / FC / BATTERY POWER SYSTEM

C. Gokul Kumar
[1](Dept. of EEE,Assistant Professor,Nandha College of Technology, Erode, Tamilnadu, India,engrgokulkumar@gmail.com)

***Abstract—****The three input dc-dc boost converter interfaces two unidirectional input power ports and a bidirectional port for a storage element in a unified structure. This converter is interesting for hybridizing alternative energy sources such as photovoltaic (PV) source, fuel cell (FC) source, and battery. Supplying the output load, charging or discharging the battery can be made by the PV and the FC power sources individually or simultaneously. This structure utilizes only four power switches that are independently controlled with four different duty ratios. Utilizing these duty ratios, tracking the maximum power of the PV source, Setting the FC power, controlling the battery power, and regulating the output voltage are provided. Depending on utilization state of the battery, three different power operation modes are defined for the converter. The aim of this project is to produce power for remote areas and to reduce the power demand to the consumer by the help of solar PV Panels, Fuel Cell and Battery. In order to design the converter control system, small-signal model is obtained in each operation mode. The control performances are verified by simulation for different operating conditions.*

***Keywords— PV system, Fuel cell, Electrolyzer, DC/DC Boost Converter.***

## 1. INTRODUCTION

### *1.1 OBJECTIVE*

To reduce the power demand the photovoltaic (PV) energy appears quite attractive for electricity generation.

To improve good voltage supporting, PV/FC hybrid system should be integrate with a fast responding storage unit with automation.

### *1.2 HYBRID POWER SYSTEM*

Since 1992, through Kyoto Treaty, there has been a growing awareness of the society regarding environmental impacts resulting from the widespread utilization of energy sources derived from petroleum. Besides, the shortage of fossil fuels solutions should be environmentally friendly solutions. Among all alternative sources, photovoltaic (PV) energy has the advantage of, being one of the primary sources that produces less pollution. PV is renewable, silent, modular and a short period of installation. Another issue which makes photovoltaic energy more attractive is linked with the fact that this system can locally generate energy, without the need of long transmission lines (which produce losses), also generating a low environmental impact and being easily integrated onto the architecture of any building.

Several stand-alone power systems installed around the world, usually located in small communities or at technical installations that are not connected to a main electricity grid. The majority of these power systems are based on fossil fuel power generation. Today there is 6.4% of the world's total use of renewable energy sources. So, there has been a growing initiative to include renewable energy technologies, particularly wind and/or solar power, into stand-alone power systems. When included in stand-alone power system, wind or solar power or both often operate in combination with diesel generators and batteries, reducing the fossil fuel consumption. Replacement of diesel generators and batteries by fuel cells running on hydrogen, produced locally with renewable energy, offers a great opportunity to improve environmental standards, and reduce operation and maintenance costs. This paper presents a proposed PV/FC/Battery hybrid power systems consists of three components. The three system components are the PV generator, fuel cell and battery.

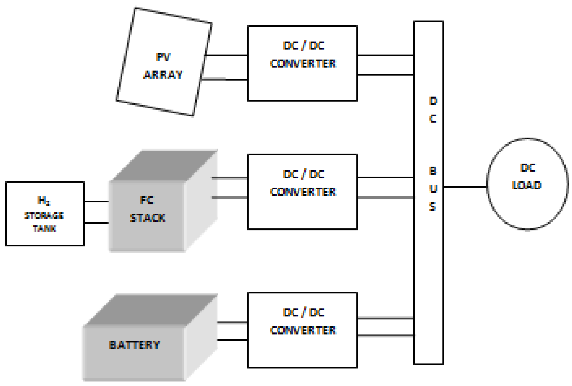



*Fig 1.1 Proposed system overview*

#### *1.2.1 Additional Source*

The power generated by PV system is highly dependent on weather conditions. Natural variations in temperature and sunlight causes power fluctuations in PV system. Some of studies of the stand-alone PV/FC hybrid power system have been reported in the literatures. To optimize, analyze and compare three hybrid power systems, i.e., PV/battery system, PV/FC system, and PV/FC/battery system. There is several simulation of hybrid PV/FC system in remote-telecom application and several designs of hybrid PV/wind systems connected to the electrical grid, including the intermittent production of hydrogen. There is addressing mismatch between intermittent solar irradiation and time-varying load demand for stand-alone PV/FC system to achieve high energy efficiency. To optimizes efficiency of the PV-electrolysis system by matching voltage and maximum power output of the PV to operating voltage of proton exchange membrane electrolyzers. To reduce these problems, we integrate PV source with other alternative power systems, and use them as a hybrid power system, that consists of a combination of two or more energy sources, converters and/or storage devices. Fuel cell is one of the attractive options to integrate with PV system. Low environmental impact, low visual impact, no noise, no emissions, no moving parts and therefore minimal maintenance requirements and small footprint are some of the FC usage advantages. PV provides the base load demand in normal condition and fuel cell is use to complement the intermittent output of the PV source.

*1.2.2 Provide Functional Upgrades*

The performances of the PV and FC systems integrate with a common DC bus through the necessary power electronic interface. Dynamic model of the fuel cell is considered. To boost low output DC voltage of the FC and PV to high DC voltage, three full-bridge DC-DC converters adopt and their controllers design. Fig1.1 shows the overall structure of purposed hybrid system.

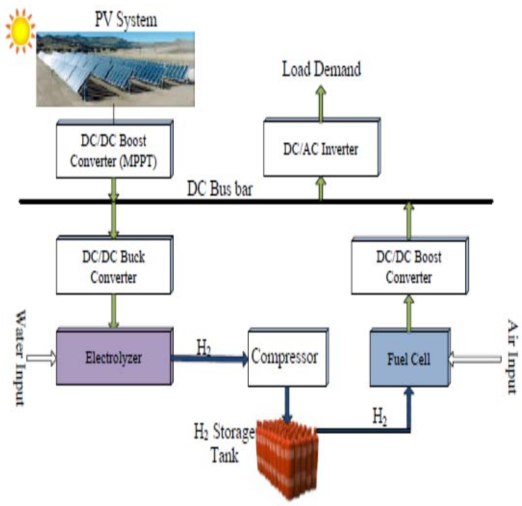



*Fig 1.2 Schematic diagram of PV/FC under compression of H2*

*1.2.3 Provide Easy Maintenance Upgrades*

The load in the proposed system overview figure stands for either a DC load or a voltage source inverter, depending on the application.

*1.2.4 Improves Performance*

A low passed filter used for connecting the converters to the DC bus. An overall control strategy will manage the power flow properly by considering the regulation of the DC bus voltage in the accepted range.

*1.2.5 Replacement of FC Inlet Management*

For the fuel cells running on hydrogen, produced locally with renewable energy, offers a great opportunity to improve environmental standards, and reduce operation and maintenance costs. This paper presents a proposed PV/FC/Battery hybrid power systems consists of five components. The five system components are the PV generator, the electrolyzer, hydrogen storage tanks, fuel cell and battery.

## 2. LITERATURE SURVEY

*2.1 HIGH EFFICIENCY HIGH POWER BOOST DC/DC CONVERTERS FOR PHOTOVOLTAIC APPLICATIONS [J. DAWIDZIUK, 2011]*

Recent environmental issues have accelerated the use of more efficient and energy saving technologies in renewable energy systems. High power high efficiency boost DC/DC converters for the use in photovoltaic, fuel cell systems are discussed in this paper from the viewpoint of power losses and efficiency. The energy storage components such as batteries, and ultra capacitors which are used in the power trains of hybrid electric vehicles, electric vehicles, and fuel cell vehicles. In the modern power drive, the voltage levels of the energy storage devices are predominantly low when the motors of the vehicles are driven at much higher voltages. In the computer industry and in the telecommunication batteries with low voltage levels are utilized as a back-up power source. State of the art converters with switching frequency within the range of 25 kHz with IGBTs to 100 kHz with power MOSFETs and the highest efficiency close to 98%, depending on the load conditions, is considered. A comparison and discussion of the highest efficiency high power DC/DC boost converters is also presented in this paper.

*2.2 CLOSED-LOOP MAXIMUM POWER POINT TRACKER FOR SUBWATT PHOTOVOLTAIC PANELS [OSCAR LÓPEZ-LAPEÑA, MARIA TERESA PENELLA, AND MANEL GASULLA, MARCH 2012]*

This paper proposes a closed-loop maximum power point tracker (MPPT) for sub-watt photovoltaic (PV) panels used in wireless sensor networks. Both high power efficiency and low circuit complexity are achieved. A microcontroller (μC) driven by a fast clock was used to implement an MPPT algorithm with a low processing time. This leads to a maximum central-processing-unit duty cycle of 6% and frees the μC to be used in the remaining tasks of the autonomous sensor, such as sensing, processing, and transmitting data. In order to reduce power consumption, dynamic power management techniques were applied, which implied the use of predictive algorithms. In addition, the measurement and acquisition of the output current and voltage of the PV panel, which increase circuit complexity, was avoided. Experimental measurements showed power consumptions of the MPPT controller as low as 52 μW for a 2.7-mW PV power and up to 388 μW for a 94.4-mW PV power. Tracking efficiency was higher than 99.4%. The overall efficiency was higher than 90% for a PV panel power higher than 20 mW. Field measurements showed an energy gain 15.7% higher than that of a direct-coupled solution.

*2.3 WIND / PV / BATTERY HYBRID POWER SYSTEM WITH PERFORMANCE ANALYSIS [A. YASIN, G. NAPOLI, M. FERRARO AND V. ANTONUCCI, 29 DECEMBER 2011]*

Time domain performance analysis results of a standalone hybrid system are presented based on commercial wind generator, photovoltaic generator and battery energy storage system. The hybrid system is designed and modelled using Matlab/ Simulink/

SimPowSys™ environment, a control strategy has been proposed to control the voltage DC bus and the energy flow between the different energy sources. The wind and photovoltaic generators are controlled locally to obtain the maximum power extraction, while battery energy storage system is controlled using specific control strategy depending on the voltage of the DC bus and energy flow. To test the performance of the system three different cases were analyzed; one case is the examination of the system performance when the photovoltaic generator is excluded from the system, the second case excludes wind energy generator while the third case includes all the sources. Each case contains various operating conditions and disturbances of load and weather data. The frequency deviation, stability of DC bus voltage and voltage total harmonic distribution are taken as system performance indexes. The simulation results ensure the effectiveness of the proposed hybrid system control strategy in following up the variations in load demand and weather data, providing the ground for practical realization.

### 2.4 DESIGN OF A SIMPLE AND CHEAP WATER ELECTROLYSER FOR THE PRODUCTION OF SOLAR HYDROGEN [R. PRASAD, 19 AUGUST 2009]

Commercially available conventional alkaline electrolyser and advanced polymer membrane electrolysers for water electrolysis are quite expensive. Taking into account this aspect, a very simple and cheap water electrolyser has been designed and fabricated utilising easily available economical materials for small scale production of hydrogen using renewable energy from photovoltaic panel. The construction details of the electrolyser with a schematic drawing of the experimental set-up for PV production of H2 are given. In order to fabricate the compact electrolyser, two coaxial tubular PVC pipes were used. The lower part of the inner pipe has fine perforations for the transport of ions through electrolyte between the electrodes. Two cylindrical electrodes, cathode and anode are kept in inner and outer pipes respectively. Hydrogen as an important future energy carrier is well established and the world's current use of fossil fuels as the primary energy source is not sustainable and also causing disastrous environmental pollution and climate change. It is emphasized that the global environmental damage caused thermodynamically is more alarming to life on earth than the risk of exhausting the finite amount of fossil fuels being consumed at the present rate. The performance of hydrogen production was measured using a photovoltaic panel directly connected to the electrolyser under atmospheric pressure and in 27wt% KOH solution. Flow rates of hydrogen and oxygen were measured using a digital flow meter. High purity fuel cell grade hydrogen (99.98%) and oxygen (99.85%) have been produced. The experimental results confirm that the present electrolyser has eligible properties for hydrogen production in remote areas. No such electrolyser has been reported prior to this work.

### 2.5 TRANSIENT RESPONSE ANALYSIS FOR DC-DC BOOST CONVERTER [CHARLES MULING ANAK LIBAU, JULY 2012]

DC-DC Boost Converter and Hybrid Posicast Controller is developed and simulated using MATLAB Simulink software. DC-DC Boost converter has a very high overshoot and a very high settling time which produce oscillated output response. In order to overcome this weakness, Hybrid Posicast Controller is used in order to regulate the output voltage to a desire value. Hybrid Posicast Controller operated within the feedback loop of the system. Transfer function of DC-DC Boost Converter are derived and Posicast elements of and can be calculated directly from the transfer function. Single gain, is used in order to eliminate the overshoot and minimize the settling time. Simulation results show that Hybrid Posicast Controller effectively regulate the output voltage to a desire value even though load resistance and duty cycle have been changed with a various values. DC-DC Boost Converter using Posicast Controller has an excellent performance to overcome unregulated input voltage, eliminate overshoot and minimize the settling time.

### 2.6 BIDIRECTIONAL DC-DC POWER CONVERTER DESIGN OPTIMIZATION, MODELING AND CONTROL [JUNHONG ZHANG, 30 JANUARY 2008]

In order to increase the power density, the discontinuous conducting mode (DCM) and small inductance is adopted for high power bidirectional dc-dc converter. The DCM related current ripple is minimized with multiphase interleaved operation. The turn-off loss caused by the DCM induced high peak current is reduced by snubber capacitor. The energy stored in the capacitor needs to be discharged before device is turned on. A complementary gating signal control scheme is employed to turn on the non-active switch helping discharge the capacitor and diverting the current into the anti-paralleled diode of the active switch. This realizes the zero voltage resonant transition (ZVRT) of main switches. This scheme also eliminates the parasitic ringing in inductor current. This work proposes an inductance and snubber capacitor optimization methodology. The inductor volume index and the inductor valley current are suggested as the optimization method for small volume and the realization of ZVRT. The proposed capacitance optimization method is based on a series of experiments for minimum overall switching loss. According to the suggested design optimization, a high power density hardware prototype is constructed and tested. The experimental results are provided, and the proposed design approach is verified. In this dissertation, a general-purposed power stage model is proposed based on complementary gating signal control scheme and derived with space-state averaging method. The model features a third-order system, from which a second-order model with resistive load on one side can be derived and a first-order model with a voltage source on both sides can be derived. This model sets up a basis for the unified controller design and optimization. The type model of coupled inductor is introduced and simplified to provide a more clearly physical meaning for design and dynamic analysis. These models have been validated by the Simplis ac analysis simulation. For power flow control, a unified controller concept is proposed based on the derived general-purposed power stage model. The proposed unified controller enables smooth bidirectional current flow. Controller is implemented with digital signal processing (DSP) for experimental verification. The inductor current is selected as feedback signal in resistive load, and the output current is selected as feedback signal in battery load. Load step and power flow step control tests are conducted for resistive load and battery load separately. The results indicate that the selected sensing signal can produce an accurate and fast enough feedback signal. Experimental results show that the transition between charging and discharging is very smooth, and there is no overshoot or undershoot transient. It presents a seamless transition for bidirectional current flow. The smooth transition should be attributed to the use of the complementary gating signal control scheme and the proposed unified controller. System simulations are made, and the results are provided. The test results have a good agreement with system simulation results, and the unified controller performs as expected.

### *2.7 MODELING AND SIMULATION OF GRID-CONNECTED HYBRID PHOTOVOLTAIC/BATTERY DISTRIBUTED GENERATION SYSTEM [M. MAKHLOUF, F. MESSAI AND H. BENALLA, JANUARY 2012]*

Compared to the traditional energy resources, photovoltaic (PV) system that uses the solar energy to produce electricity considered as one of renewable energies has a great potential and developing increasingly fast compared to its counterparts of renewable energies. Such systems can be either stand-alone or connected to utility grid. However, the disadvantage is that PV generation depended on weather conditions. Thus, the battery energy storage is necessary to help get a stable and reliable output from PV generation system for loads and improve both steady and dynamic behaviours of the entire generation system. This paper presents detailed modelling of the grid-connected PV/Battery hybrid generation system components, in Simulink / MATLAB software. PV array is connected to the common dc bus through a boost converter, where the battery is also connected by a buck-boost DC/DC converter, and then integrated into the ac utility grid through a three phases DC/AC inverter. Maximum power point tracking makes PV array generating the maximum power to the grid, and the battery energy storage can be charged and discharge to balance the power flow between PV generation and utility grid. Simulation results presented here validate the component models and the chosen control schemes.

### *2.8 STAND ALONE HYBRID POWER SYSTEM BASED ON PHOTOVOLTAIC, FUEL CELL AND BATTERY [M.KARAMI AND S.LESAN, OCTOBER 2010]*

This paper presents an optimal power management strategy in a stand-alone hybrid power system based on photovoltaic (PV), fuel cell (FC) and Battery sources. PV provides the basic load demand in normal condition and the FC/Battery combination used as a backup source. FC used to complement the intermittent output of the PV source. Because of the slow dynamic response of the FC, in fast step loading, battery storage used to compensate that part of the temporary peak demand, which the PV and FC could not meet that. By sizing the battery to supply the peaking load in surplus of what can be meet by the FC and PV, the fuel cell can be size only for the average load, thus avoiding oversized of fuel cell. At First, the structure of the hybrid power system and then control strategies for optimal power management with considering the output voltage regulation will be discuss. It will be model and simulated using MATLAB / Simulink software package.

### *2.9 RENEWABLE ENERGY SOURCES AND HYBRID GENERATING SYSTEMS [GHOLAMREZA ESMAILI, 2006]*

In general, this dissertation discusses application of advanced power electronics in small size wind energy and hybrid generating systems.

A new and simple control method for maximum power tracking by employing a step-up dc-dc boost converter in a variable speed wind turbine system, using permanent magnet machine as its generator, is introduced. Output voltage of the generator is connected to a fixed dc-link voltage through a three-phase diode rectifier and the dc-dc boost converter. A maximum power-tracking algorithm calculates the reference speed, corresponds to maximum output power of the turbine, as the control signal for the dc-dc converter. The dc-dc converter uses this speed command to control the output power of the generator, by controlling the output voltage of the diode rectifier and input current of the boost converter, such that the speed of generator tracks the command speed. A current regulated pulse width modulation voltage source inverter maintains the output voltage of the dc-dc converter at a fixed value by balancing the dc-link input and output power.

Moreover, a new and simple speed estimator for maximum power tracking and a novel vector control approach to control the output voltage and current of a single-phase voltage source inverter are introduced. Using the proposed speed estimator, the system only needs two measurements to estimate the generator speed and implement the maximum power-tracking algorithm. Furthermore, since the system maintenance is very important and in wind energy systems the generator is not easily assessable, a robust technique for on-line condition monitoring of stator windings is introduced. In this technique the generator terminal voltage and current are utilized as input signals; therefore, this method could help to monitor the stator winding condition very efficiently to prevent catastrophic failure. The generating system has potentials of high efficiency, good flexibility, and low cost.

This dissertation also proposes a hybrid energy system consisting of a wind turbine, a photovoltaic source, and a fuel cell unit designed to supply continuous power to the load. A simple and economic control with dc-dc converter is used for maximum power extraction from the wind turbine and photovoltaic array. Due to the intermittent nature of both the wind and photovoltaic energy sources, a fuel cell unit is added to the system for the purpose of ensuring continuous power flow. The fuel cell is thus controlled to provide the deficit power when the combined wind and photovoltaic sources cannot meet the net power demand. The proposed system is attractive owing to its simplicity, ease of control and low cost. Also it can be easily adjusted to accommodate different number of energy sources. A complete description of this system is presented along with its simulation results which ascertain its feasibility.

The last part of the dissertation focuses on the design of a novel Power Conversion System (PCS), which can be used to convert the energy from the hybrid system into useful electricity and provide requirements for power grid interconnections. The motivation behind developing such a PCS is to reduce the overall cost of hybrid systems and thus result in increased penetration into today's energy scenario.

*2.10PHOTOVOLTAIC / WIND / FUEL CELL HYBRID GENERATION SYSTEM [M.MAHALAKSHMI AND DR.S.LATHA, MAY 2012]*

The depleting fossil fuel reserves and increasing concern towards global warming have created the need to surge for the alternative power generation options. Renewable energy sources like Wind, Solar-PV, Biomass and fuel cells are gaining prominence nowadays, as they are more energy efficient, reduce pollution and also they serve as a promising solution to the toughest energy crisis faced during the recent years. This paper focuses on the modeling and simulation of solar – photovoltaic, wind and fuel cell hybrid energy systems using MATLAB/Simulink software. The intermittent nature of solar and wind energy sources make them unreliable. Hence Maximum Power Point Tracking (MPPT) is used to extract maximum power from the wind and sun when it is available. The standard perturb and observe method of MPPT is used for the PV system and for the wind generation system. The simulation results of the PV/Wind /Fuel cell hybrid system are presented in graph showing the effectiveness of the proposed system model. Also, hardware implementation of microcontroller based MPPT for solar-PV alone and unit sizing of the hybrid system for the PG simulation lab in EEE Dept. of Thiagarajar College of Engineering is depicted in the paper.

*2.11SUN TRACKING SYSTEMS [CHIA-YEN LEE, PO-CHENG CHOU AND CHE-MING CHIANG, MAY 2009]*

The output power produced by high-concentration solar thermal and photovoltaic systems is directly related to the amount of solar energy acquired by the system, and it is therefore necessary to track the sun's position with a high degree of accuracy. Many systems have been proposed to facilitate this task over the past 20 years. Accordingly, this paper commences by providing a high level overview of the sun tracking system field and then describes some of the more significant proposals for closed-loop and open-loop types of sun tracking systems.

*2.12MARS ROVERS: PAST, PRESENT AND FUTURE [DONNA L. SHIRLEY, JACOB R AND MATIJEVIC, 10 MAY 1997]*

Since the 1960's there have been efforts world-wide to develop robotic mobile vehicles for traversing planetary surfaces. Two Lunakhods wer successfully operated on the Moon in the early1970s, but since then there have been no planetary overs. Developments in mobility, navigation, power, computation, and thermal control have now allowed a small, 11.5 kg rover named Sojourner Truth to beheading for Mars. Sojourner Witt explore an area within site of the Pathfinder lender's camera, making measurements of the surface properties, and imaging rocks and obtaining their elemental composition .Future U. S., and perhaps Russian rovers are planned to go to Mars in 2001, 2003, 2007 and 2011 to rove10 kilomctcm or so and collect samples for return to earth by missions launched in 2005, 2009 and 2013.

*2.13SOLERO SOLAR POWERED EXPLORATION ROVER [S.MICHAUD, A. SCHNEIDER, R.BERTRAND AND P.LAMON, NOVEMBER 2002]*

A mobile robot is the most suited element to bring scientific instruments to a specific site in order to examine geology, mineralogy or exobiology on extraterrestrial planets. In contrast with the Mars Pathfinder mission, the actual need for mobility increases in terms of range and duration. In this respect, redesigning specific aspects of the past rover concepts, in particular the development of most suitable all terrain performances, autonomous navigation and a power management concept is appropriate. Labeled SOLERO ("Solar-Powered Exploration Rover") this activity has the objective to develop a system design for a regional exploration rover including bread boarding for demonstration of locomotion capabilities, payload accommodation, power provision, and control. In this paper we will focus on the locomotion and the energy management.

2.14*DYNAMIC POWER PATH MANAGEMENT SIMPLIFIES BATTERY CHARGING FROM SOLAR PANELS [NIGEL SMITH, OCTOBER 2006]*

The Texas Instruments bq2403x family of linear charge regulators was originally designed to charge single-cell Li-ion batteries from an AC adapter or USB port. However, these ICs also lend themselves well to applications powered by solar panels. Solar cells basically comprise a p-n junction in which incident light energy causes electrons and holes to recombine, generating an electric current. As the p-n junction's characteristics are similar to those of a diode, the electrical circuit shown in is often used as a simplified model of the cell's characteristics.

*2.15LITHIUM BATTERIES FOR AEROSPACE APPLICATIONS: 2003 MARS EXPLORATION ROVER [B.V.RATNAKUMAR, M.C.SMART, A.KINDLER, H.FRANK, R.EWE AND S.SURAMPUDIM]*

Future NASA planetary exploration missions require batteries that can operate at extreme temperatures and with high specific energy and energy densities. Conventional aerospace rechargeable battery systems, such as Ni-Cd and Ag-Zn, are inadequate to meet these demands. Lithium ion rechargeable batteries are therefore being chosen as the baseline for these missions. The 2003 Mars Exploration Rover mission plans to deploy twin rovers onto Mars, with the objectives of understanding its geology, climate conditions and possibility of life on Mars.
The spacecraft contain various batteries, i.e., primary batteries on the lander, thermal batteries on the back shell and rechargeable batteries on the Rovers. Significant among the mare the Li ion rechargeable batteries, which are being utilized for the first time in a major NASA mission. The selection of the Li ion battery has been dictated by various factors, including mass and volume constraints, cycle life, and its ability to operate well at sub-zero temperatures at moderate rates. This paper describes the selection criteria, design and performance of the three battery systems on 2003 MER mission.

*2.16JAPANESE ROVER TEST-BED FOR LUNAR*

*EXPLORATION [TAKASHI KUBOTA, YASUHARU KUNII AND YOJI KURODA, SEPTEMBER 2007]*

Lunar exploration missions including landesr and rovers are earnestly under studying in Japan. One of main missions for lunar robotics exploration is to demonstrate the technologies for lunar or planetary surface exploration. They will cover landing technology and surface exploration rover technology. Lunar geologic survey will be also performed for utilization and scientific investigation of the moon. The working group has been conducting the feasibility study of advanced technologies for lunar robotics exploration. Unmanned mobile robots are expected for surface exploration of the moon, because mobile robots can travel safely over a long distance.

*2.17 EXPERIMENTS AND ANALYSIS OF THE ROLE OF SOLAR POWER IN LIMITING MARS ROVER RANGE [D.VILLA AND M.WANGNER, 2007]*

A common explanation for the limited distance travelled by NASA's past and planned Mars rovers is the limits of solar power. This paper explores this hypothesis and documents a series of experiments with a solar powered rover. A detailed comparison between our rover and Sojourner, with regards to power usage, is presented. Experiments and analysis clearly show that other factors dominate in limiting the range of NASA's solar powered robots when operating on Mars.

*2.18 PHOTOVOLTAIC SUB-MODULE INTEGRATED CONVERTER ANALYSIS [SOURAV SEN, AUGUST 2012]*

With the rapid expansion of the photovoltaic industry over the last decade, there has been a huge demand in the PV installations in the residential sector. This thesis focuses on the analysis and implementation of a dc-dc boost converter at photovoltaic sub-module level. The thesis also analyses the various topologies like switched capacitors and extended duty ratio which can be practically implemented in the photovoltaic panels. The results obtained in this work have concentrated on the use of novel strategies to substitute the use of central dc-dc converter used in PV module string connection. The implementation of distributed MPPT at the PV sub-module level is also an integral part of this thesis.

Using extensive PLECS simulations, this thesis came to the conclusion that with the design of a proper compensation at the dc interconnection of a series or parallel PV Module Integrated Converter string, the central dc-dc converter can be substituted. The dc-ac interconnection voltage remains regulated at all irradiance level even without a dc-dc central converter at the string end. The foundation work for the hardware implementation has also been carried out. Design of parameters for future hardware implementation has also been presented in detail in this thesis.

*2.19 TWO-PHASE BOOST CONVERTER [TADEUS GUNAWAN, DECEMBER 2009]*

A boost converter is one of the most efficient techniques to step up DC input voltage to a higher needed DC output voltage. The boost converter has many possible applications, such as in a photovoltaic system, hybrid car and battery charger. The proposed prototype in this report is a proof of concept that a Two-Phase Boost Converter is a possible improvement topology to offer higher efficiency without compromising any advantages readily offered by a basic boost. The prototype is designed to be able to handle up to 200 watts of output power with an input of 36 volts and an output of 48 volts. This paper goes through step-by-step the calculation, design, build and test of a Two-Phase Boost Converter. Calculations found in this paper were done on Mathcad and the simulations were done on LT Spice and P Spice. These include converter’s efficiency and other measures of converter’s performance. Advantages, disadvantages as well as possible improvements of the proposed topology will be presented. Data collected and analyzed from the prototype were done on a bench test, not through an actual application.

## 3. SYSTEM ANALYSIS

*3.1 EXISTING SYSTEM*

The hybridizing alternative energy sources, using duty ratios, tracking the maximum power of the PV source, setting the FC power, controlling the battery power, and regulating the output voltage are provided. Depending on utilization state of the battery, three different power operation modes are defined for the converter. In order to design the converter control system, small-signal model is obtained in each operation mode. Due to interactions of converter control loops, decoupling network is used to design separate closed-loop controllers.

*Drawbacks*

The main drawbacks in existing system are explained as follows:

- When there is no or low solar radiation, the PV system can’t provide sufficient electricity to feed load demand, the fuel cell will utilize H2 to produce electricity for the load demand. Note that the electrolyzer and the fuel cell will not be operated simultaneously.
- The switching over time between two pack of batteries takes long Period to perform its operation.

*3.2 PROPOSED SYSTEM*

During solar radiation, Power will be generated by PV system to feed load demand and the excess power will be compressed and stored in the form of hydrogen in a storage tank. If there is no or low solar radiation, the PV system can’t provide sufficient electricity to feed load demand, the fuel cell will utilize H2 to produce electricity for the load demand.

## 4. SOFTWARE DESCRIPTION

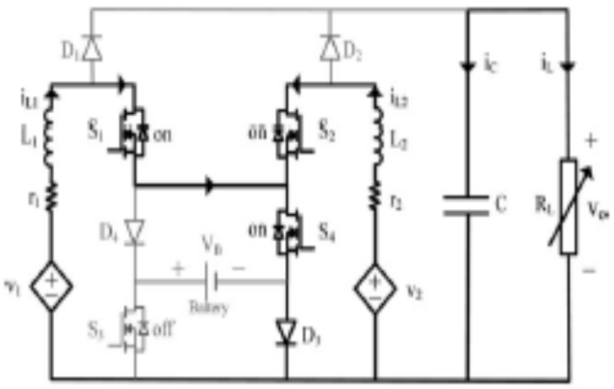
*4.1 MATLAB / SIMULINK*

The proposed model of the entire components and control system are all simulated under MATLAB / SIMULINK software. Here there are three different cases are simulated for the hybrid PV / FC / Battery system, and all simulation results have verified the validity of models and effectiveness of control methods.

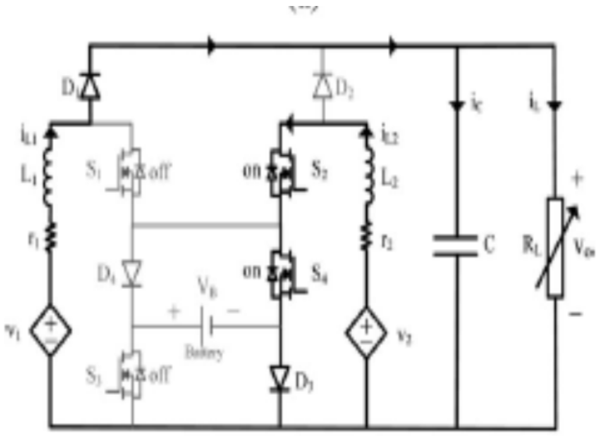
## 5. PROJECT DESCRIPTION

*5.1 FIRST OPERATION MODE*

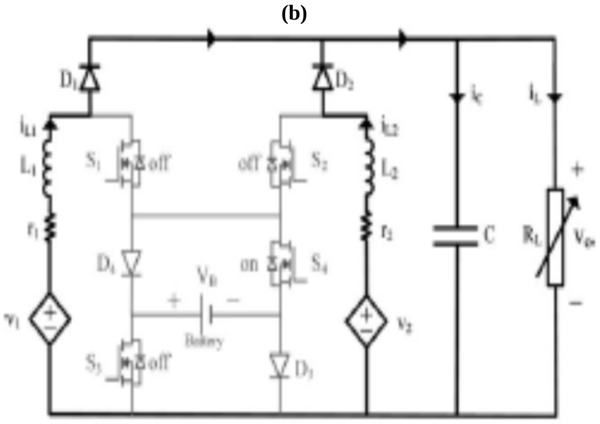
Supplying the Load With Sources v1 and v2 Without Battery Existence



**(a)**

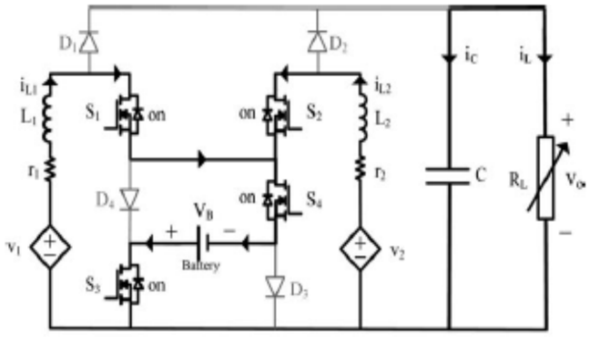


**(b)**

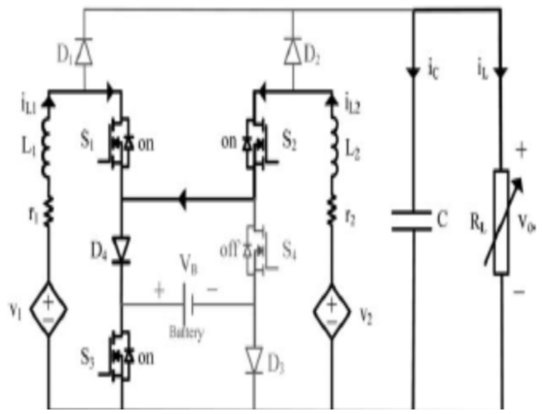


**(c)**

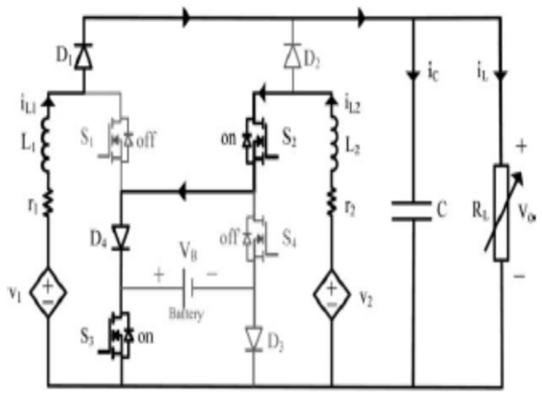
Fig 5.1 First operation mode:
(a) Switching state 1: 0< t< d1 T.
(b) Switching state 2: d1 T< t < d2 T.
(c) Switching state 3: d2 T < t < T.



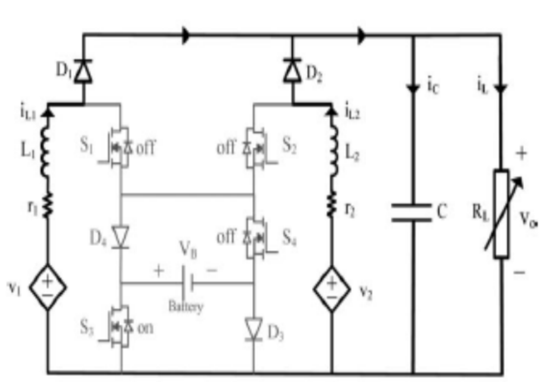
**(a)**



**(b)**



**(c)**



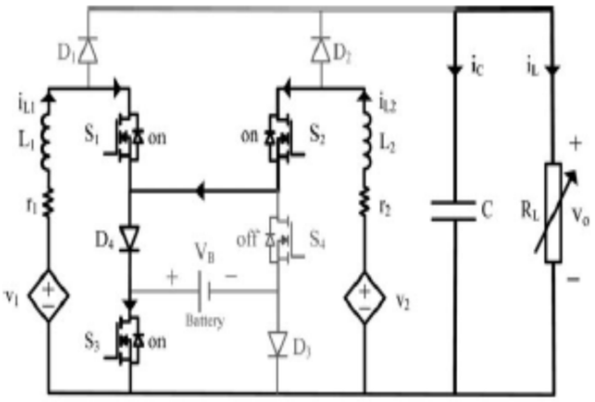
**(d)**

*5.2 SECOND OPERATION MODE*

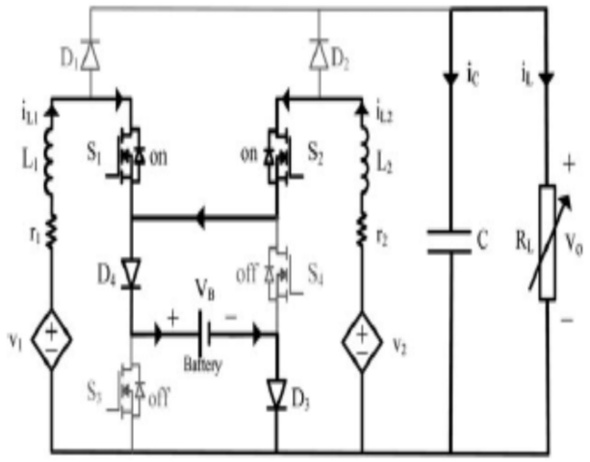
Fig 5.2 Second operation mode:

(a) Switching state 1: 0 < t < d4 T.
(b) Switching state 2: d4 T< t < d1 T.
(c) Switching state 3: d1 T < t < d2 T.
(d) Switching state 4: d2 T < t < T.

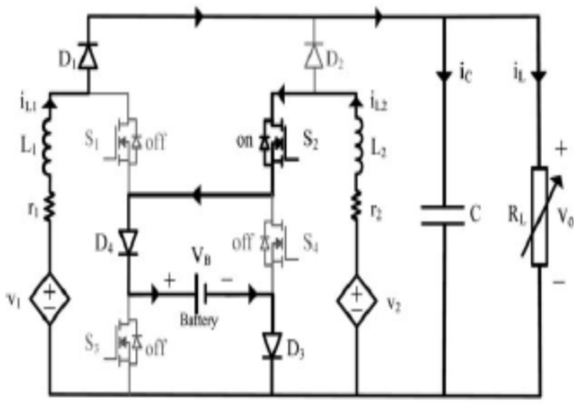
### *5.3 THIRD OPERATION MODE*



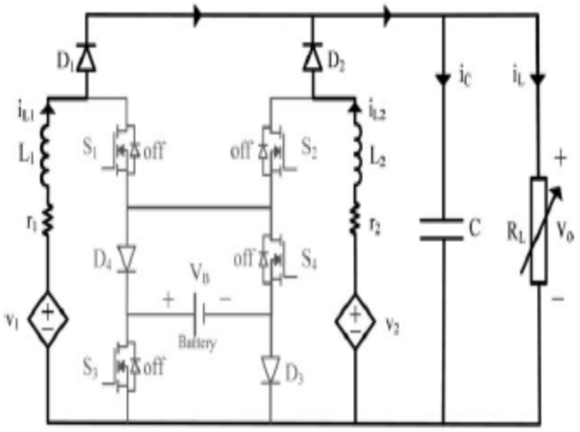

**(a)**




**(b)**




**(c)**




**(d)**

Fig 5.3 Third operation mode:
(a) Switching state 1: 0< t< d3 T.
(b) Switching state 2: d3 T< t < d1 T.
(c) Switching state 3: d1 T < t < d2 T.
(d) Switching state 4: d2 T < t < T.

## 6. SYSTEM IMPLEMENTATION

### *6.1 OPERATIONAL CONTROL STRATEGIES*

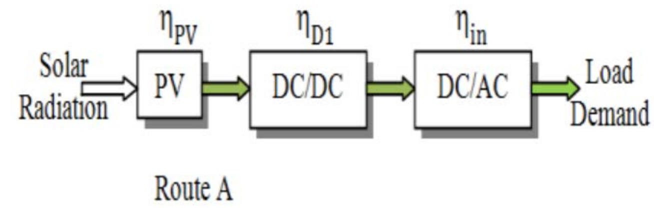
The Fig. 6.1 shows four corresponding routes of energy flow within stand-alone PV/FC system. To ensure the highest realizable efficiency and the best possible supply security of the stand-alone PV/FC system, the operational strategies have to be stated with care, which is summarized below.

- When PV electrical power is equal to the load demand, PLoad, route A will be employed to transfer electricity from the PV system to the load demand.
- When PV electrical power exceeds the load demand, PLoad, route B will be employed to transfer electricity from the PV system to the load demand and the excess electricity would be inputted into the electrolyzer to produce H2. If the H2 storage tanks become full, the excess power will be diverted to another dump load.
- When PV electrical power less than the load demand, PLoad, route C will be employed to transfer electricity from both the PV system and the fuel cell.
- When there is no solar radiation, route D will be employed to transfer electricity from the fuel cell only to the load demand. Summary of the operational control strategies is shown in table 6.1.

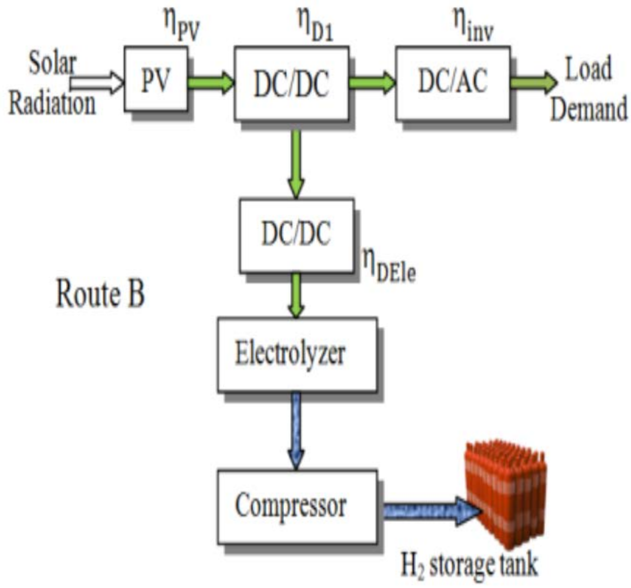
Table 6.1 Operational Control Strategies

| Route | Generated power vs Load demand |
|---|---|
| A | $P_{pv} = P_{Load}$ |
| B | $P_{pv} > P_{Load}$<br>A control signal will be sent to Electrolyzer to operate |
| C | $P_{pv} < P_{Load}$<br>A control signal will be sent to Fuel cells to operate |
| D | Ppv =0<br>A control signal will be sent to fuel cells to feed the |

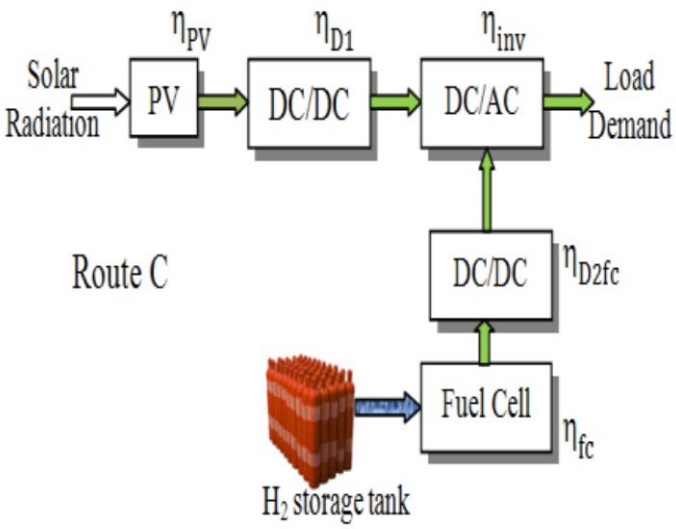
| | |
|---|---|
| | load demand. |



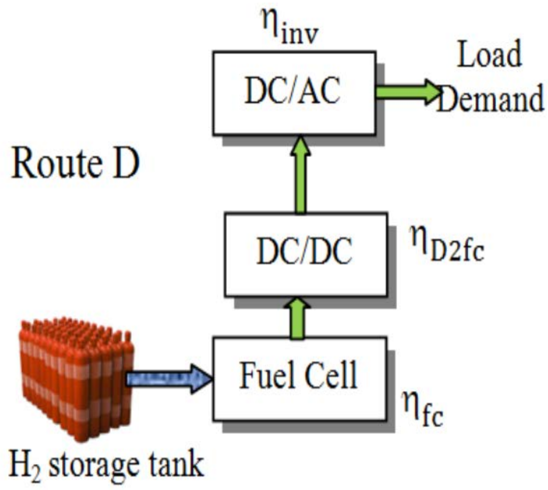

**(a)**




**(b)**




**(c)**




(d)

*Fig 6.1 Operation control strategies of the PV/FC system*

## 7. SIMULATION RESULTS

### *7.1 MEASURING PARAMETERS*

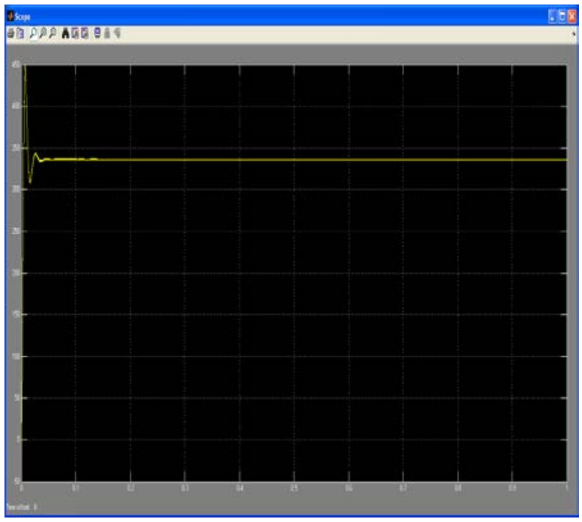


*Fig 7.1 Load voltage waveform*

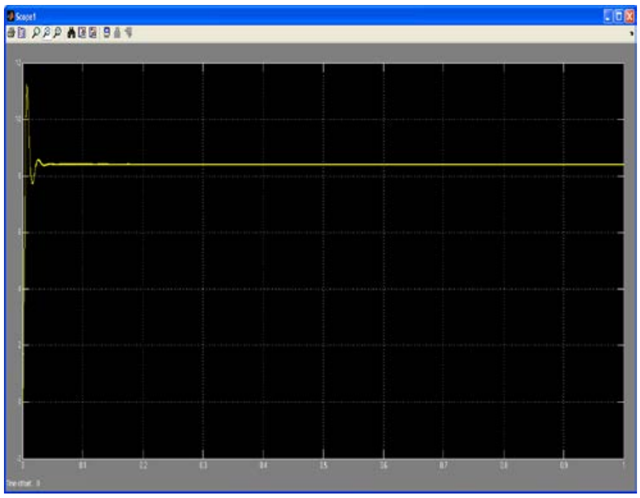


*Fig 7.2 Load current waveform*

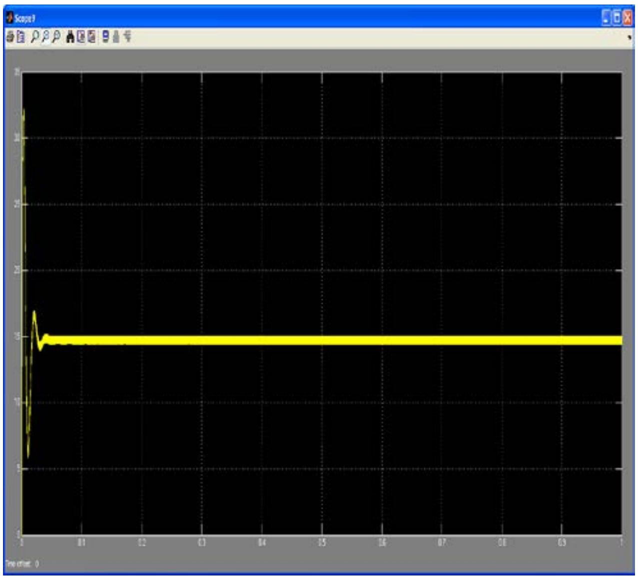


*Fig 7.3 Fuel cell current*

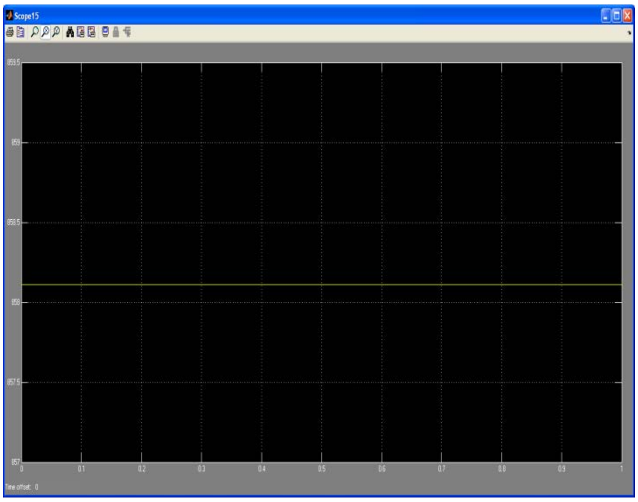


*Fig 7.4 Power generated in solar panel at radiation = 500*

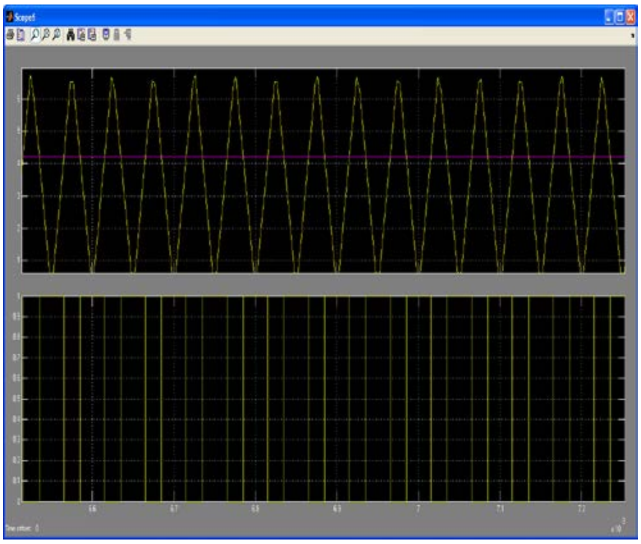


*Fig 7.5 Control signal to MOSFET*

## 8. CONCLUSION & FUTURE ENHANCEMENTS

### *8.1 CONCLUSION*

The PEM fuel cells are a viable alternative to diesel engine generators as renewable, clean, safe energy and high efficiency for the next century. PEM fuel cell technology, while still facing economic and technical hurdles on the way to becoming a popular energy supply alternative, can now claim to be a durable and reliable choice for power system generation. PV/FC/Battery hybrid power system is proposed as an ultra low emission energy system. Computer program and control strategies have been developed to coordinate the optimal design and operation of the PV/FC/Battery hybrid power system components. The proposed control strategy can be easily adapted and applied to similar renewable energy systems which contain multiple components working together.

### *8.2 FUTURE ENHANCEMENTS*

In case of no or low solar radiation the PV system cannot provide sufficient power, for that the FC is in need to satisfy the demand, since its batteries in line could not be recharged when depleted. The future work focuses on the design and construction of the storage tank for hydrogen and oxygen. The aim is to generate hydrogen and oxygen from the excess generated Power in PV. The H2 and oxygen are furnished to fuel cells, which is used to run smoothly and without interruption, supply the load. Thus, the implementation of a complete energy management system applied to a hybrid is put forward. On the one hand, it presents the construction of a solar tracking mechanism aimed at increasing power.

## REFERENCES

[1] M. Daous , M. Bashir, M. El-Naggar ,Experiences with the Safe Operation of a 2 kW Solar Hydrogen Plant, International Journal Hydrogen Energy 19, 1994, 441-445.

[2] S. H. Karaki, R. B. Chedid, R. Ramadan, Probabilistic Performance Assessment of Autonomous Solar-wind Energy Conversion Systems, IEEE Trans. on Energy Conversion, vol. 14, 1999, 766-722.

[3] T. Schucan, International energy agency hydrogen implementing agreement task 11: in systems: final report of subtask A: case studies of integrated hydrogen energy systems, IEA/H2/TII/FR1; 2000.

[4] P. Hollmuller, et. al. ,Evaluation of a 5 kWp Photovoltaic Hydrogen Production and Storage Installation for a Residential Home in Switzerland, International Journal Hydrogen Energy 25 2000, 97–109.

[5] M.S.Schneider, A.Bertrand, R.Lamon, P.Siegwart, R.vanWinnendael, and A. Schiele, (2002) "SOLERO Solar powered exploration rover," presented at the 7th ESA Workshop Advanced Space Technologies for Robotics and Automation, Noordwijk, The Netherlands.

[6] Stefano, B.V.Ratnakumar, M.C.Smart, G.Halpert, A.Kindler, H.Frank, S.Di, R.Ewell, and S.Surampudi, (2002) "Lithium batteries on 2003 mars exploration rover," presented at the IEEE 17th Annu. Battery Conf. Applications and Advances, Long Beach, CA, pp. 47–51.

[7] P. Ghosh et. al. ,Ten years of Operational Experience with a Hydrogen-based Renewable Energy Supply System, Solar Energy 75, 2003, 469–78.

[8] H. Miland ,Operational Experience and Control Strategies for a Stand-Alone Power System based on Renewable Energy and Hydrogen, Ph. D. Thesis, in : Norwegian University of Science and Technology, Faculty of Natural Sciences and Technology Department of Materials Technology, ISBN-number: 82-471-6919-3, February 2005.

[9] N.Smith, (2006) “Dynamic power path management simplifies battery charging from solar panels,” Texas Instruments, Dallas, TX, Tech. Rep. SLUA394.

[10] G. Tina, S. Gagliano, S. Raiti ,Hybrid Solar/wind Power System Probabilistic Modeling for Long-term Performance Assessment,. Solar Energy 80, 2006, 578–588.

[11] L.E.Ray, J.H.Lever, A.D.Streeter, and A.D.Price, (2007) “Design and power management of a solar-powered cool robot for polar instrument networks,” J. Field Robot., vol. 24, no. 7, pp. 581–599.

[12] T.Jinayim, S.Arunrungrasmi, T.Tanitteerapan, and N.Mungkung, (2007) “Highly efficient low power consumption tracking solar cells for white-LED based lighting system,” World Acad. Sci., Eng. Technol., vol. 28, pp. 291–296.

[13] M.Bajracharya, M.W.Maimone, and D.Helmick, (2008) “Autonomy for mars rovers Past, present, and future,” Computer, vol. 41, no. 12, pp. 44–50.

[14] T.Kubota, Y.Kunii, Y.Kuroda, and M.Otsuki, (2008) “Japanese rover test- bed for lunar exploration,” in Proc. Int. Symp. Artif. Intell., Robot. Automat. Space, no.77.

[15] M. Beccali, et. al ,Energy, Economic and Environmental Analysis on RET-hydrogen Systems in Residential Buildings, Renewable Energy 33, 2008, 366–382

[16] C.Y.Lee, P.C.Chou, C.M.Chiang, and C.F.Lin, (2009) “Sun tracking systems A review,” Sensors, vol. 9, pp. 3875–3890.

[17] A.B.Afarulrazi, W.M.Utomo, K.L.Liew, and M.Zafari, (2011) “Solar tracker Srobot using microcontroller,” in Proc. Int. Conf. Bus., Eng. Ind. Appl.,pp. 47–50.

[18] Farzam Nejabatkhah, Saeed Danyali, Seyed Hossein Hosseini, Mehran Sabahi, and Seyedabdolkhalegh Mozaffari Niapour, “Modeling and Control of a New Three-Input DC–DC Boost Converter for Hybrid PV/FC/Battery Power System”, IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 27, NO. 5, MAY 2012

[19] L. William Clapper, Sun Line Transit Agency: hydrogen commercialization for the 21st century, http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/30535ah.pdf