Modeling, Control and Simulation of Integtrated Photovoltaic cell-Fuel cell-Battery based Distributed Generation System

Dileep Kumar
M.Tech, Electrical Engg.
NIT, Patna, India
Email: dlpkmr53@gmail.com

Ashiwani Kumar
Assistant Prof., Electrical Engg.
NIT, Patna, India
Email: ashiwaninit@gmail.com

Dr. Ramesh Kumar
Associate Prof., Electrical Engg.
NIT, Patna, India
Email: rknitpatna@gmail.com

Abstract— Utility restructuring, cutting-edge power electronics, public environmental concerns, and expanding power demand are providing the opportunity for emerging generation technologies in the modern world. In order to meet sustained load demands during varying natural conditions, different energy sources need to be integrated with each other for extended usage of alternative energy. The paper presents the modeling and control framework of a photovoltaic cell-battery-fuel cell(PVBFC) integrated stand-alone distributed generation system(DGS) in Matlab/Simulink environment. A new control strategy for charging and discharging controller(CDC) of generic battery(GB), maximum power point tracker(MPPT) for photovoltaic cell(PVC) and fuel flow rate controller(FRC) for fuel cell(FC) are developed. GB works in parallel with PVC to compensate varying natural conditions in day time and FC works independently at night. we have also designed an inverter model for the proposed system by considering the output voltage regulation.

Keywords-component: PVC, MPPT, PEMFC, GB, DGS, Voltage Regulation

I. INTRODUCTION

The conventional fuel energy sources such as petroleum, natural gas, and coal which meet most of the world's energy demand today are being depleted rapidly. Also, their combustion products are causing global problems such as the greenhouse effect and pollution which are posing great danger for our environment and eventually for the entire life on our planet **[**1**].** The alternative energy sources (PVC,FC,GB etc.) are attracting more attention. Today, new advances in power generation technologies and new environmental regulations encourage a significant increase of distributed energy resources(DERs) around the world. DGS has mainly been used as a Stand-alone power system[2].

A detailed approach to PVC, FC and GB modeling based on a mathematical description of the equivalent electrical circuits are given in [3-4],[5] and [6] respectively.

Tracking the maximum power point(MPP) of a photovoltaic(PV) array is usually an essential part of a PV system. Much focus has been on hill climbing [7], and perturb and observe (P&O) methods[8,9]. Hill climbing involves a perturbation in the duty ratio of the power converter, and P&O a perturbation in the operating voltage of the PV array.

The system under study in this paper is a stand-alone PVBFC integrated power system, which consists of a PVC, GB and a proton exchange membrane fuel cell(PEMFC). A simulation software program known as MATLAB/SIMULINK is used in dealing with modeling, simulation, control and energy management of the system under study. MPPT for PVC, CDC for GB and FRC for PEMFC are developed to get optimal system performance. The configuration of overall DGS system is a PVBFC integrated voltage source, a voltage source inverter (VSI) with a LC filter and an AC load.

II. MAIN COMPONENTS OF THE PROPOSED DGS

The basic components of the proposed DGS are DERs and their controllers, VSI with LC filter, and an AC load.

A. Modeling of DERs

The equivalent circuitry of a PV cell shown in Fig.1, the simplest model can be represented by a current source in parallel with a diode, and the non-idealities are represented by the insertion of the resistances Rs and Rp.

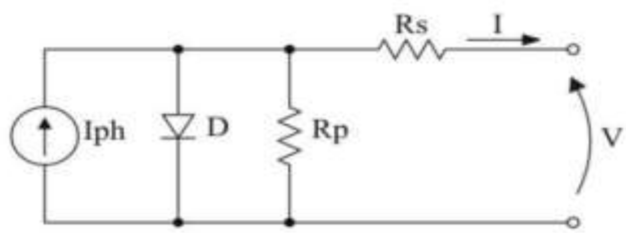

Fig.1: Equivalent Model of the Photovoltaic Panel.

$V=I_{ph} - I_d - V_d/R_p$ (1)

$I= V_d - R_s * I_{\_pv}$ (2)

$I_d=I_{sat}*\exp(V_d/V_T -1)$ (3)

$V_T=k*T/q*Q_d*N_{cell}*N_{ser}$ (4)

Where,

I_d = Diode cuurent (A)
V_d = Diode voltage (V)
R_s=Series resistance(Ω)
R_p=Shunt resistance(Ω)

I_{sat} = diode saturation current (A)
T = cell temperature (K),
V_T =temperature voltage(V)
k = Boltzman constant = 1.3806e-23 J.K$^{\wedge -1}$
q = electron charge = 1.6022e^{-19} C
Q_d = diode quality factor
N_{cell}= number of series-connected cells per module
N_{ser} = number of series-connected modules per string

B. Control Schemes for DERs

Hill climbing involves a perturbation in the duty ratio of the power converter, and P&O a perturbation in the operating voltage of the PV array. In the case of a PV array connected to a power converter, perturbing the duty ratio of power converter perturbs the PV array current and consequently perturbs the PV array voltage. A flow chart for MPPT algorithm is developed as shown in Fig.2.

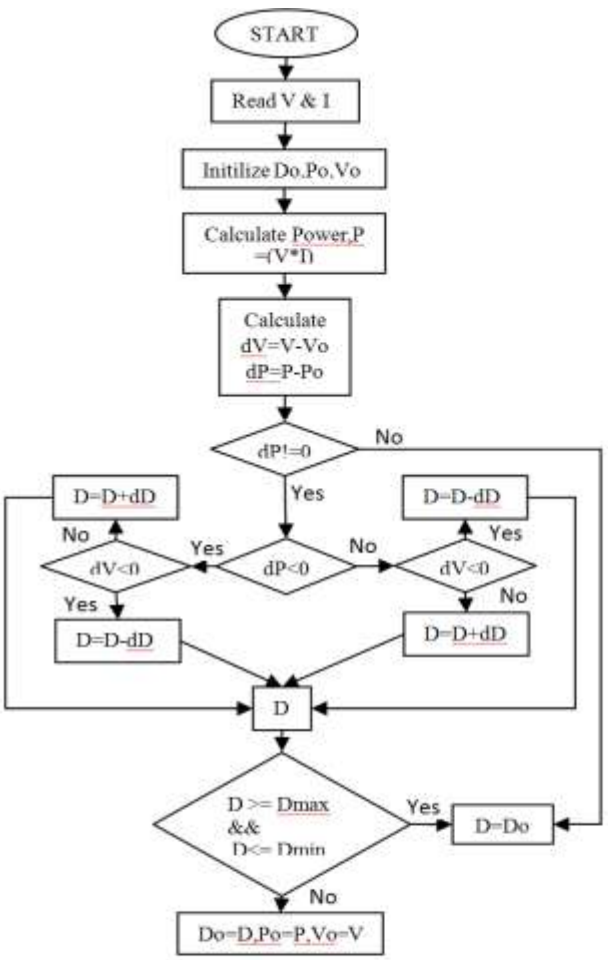

Fig. 3: Flow chart of MPPT Algorithm.

From Fig. 3, it can be seen that incrementing (decrementing) the voltage increases (decreases) the power when operating on the left of the MPP and decreases (increases) the power when on the right of the MPP. Therefore, if there is an increase in power, the subsequent perturbation should be kept the same to reach the MPP and if there is a decrease in power, the perturbation should be reversed. The process is repeated periodically until the MPP

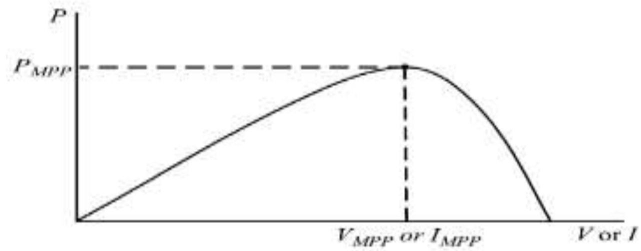

Fig.3: Maximum power point for PV Array .

is reached. The system then oscillates about the MPP. The oscillation can be minimized by reducing the perturbation step size.

The Power converter i.e the boost converter boosts DC voltage from V_{MMP} to 500V. This converter uses a MPPT system which automatically varies the duty cycle in order to generate the required voltage to extract maximum power.

Basic equation of boost converter is

(5)

Where,

Vo=Output Voltage
Vin=Input voltage
D=duty cycle

The boost converter is designed in such a way that the Vo is again regulated to fixed voltage with the help of controlled voltage source converter of 500V.

A flow chart is developed for the CDC of the battery shown in Fig.4. The battery status signal i.e state of charge(SOC) is compared with upper and lower limit of SOC(%) in which limit battery works properly.

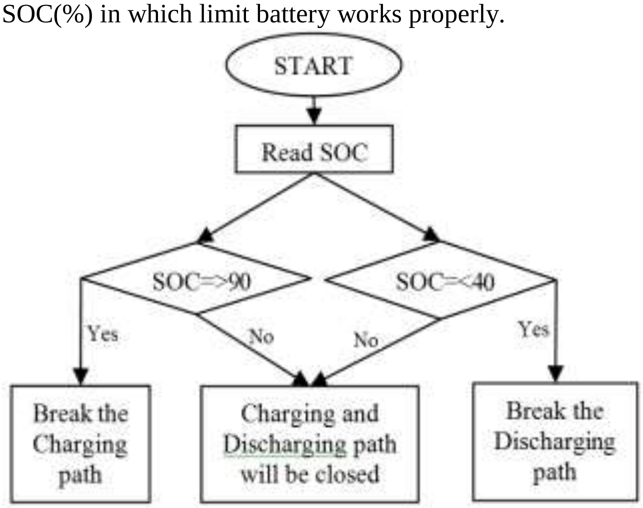

Fig.4: Flow chart for CDC of Battery.

A fuel cell current controlled fuel flow rate regulator is derived from [**5**]. The fuel flow rate is directly proportional to fuel cell current.

III. SIMULATION MODEL OF PVBFC SYSTEM

The models are integrated in SimPowerSystems(SPS) and used in a simulation of a PVBFC System. As shown in . Fig. 9 ,it consists of three DERs with their controllers, a IGBT voltage source inverter with PWM gate controller and an AC load. The four power(KW) displays show the status of power generated and observed by DERs and AC load. Additional scopes and measurements are displayed inside the subsystem block(light blue color).

A: PWM IGBT inverter

A 3-phase 6-switch DC/AC PWM voltage source inverter is used to convert the power from DC to AC. Fig. 5 shows the main circuit of a 3-phase voltage source inverter, which is actually an IGBT-diode universal bridge.

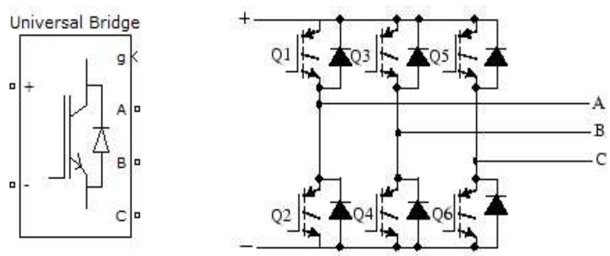

Fig. 5: IGBT-Diode Universal Bridge

This VSI needs gate pulses which are generated by PWM generator.

B: PWM Generator

The PWM Generator block generates pulses for carrier-based PWM converters using two-level topology. The block can be used to fire the forced-commutated devices (FETs, GTOs, or IGBTs) of single-phase, two-phase, three-phase, two-level bridges or a combination of two three-phase bridges.

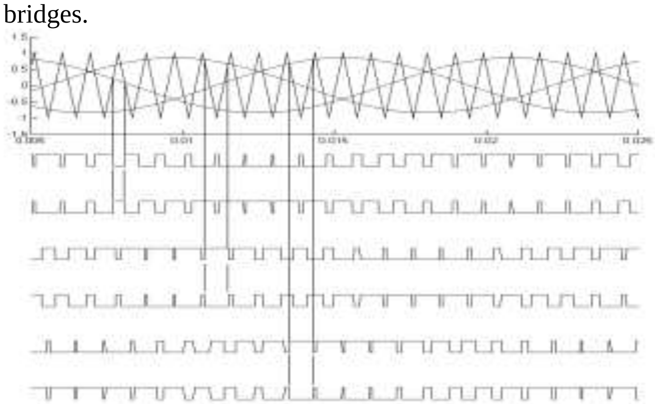

Fig. 6: Six pulses generated by the PWM Generator.

The pulses are generated by comparing a triangular carrier waveform to a reference modulating signal. The modulating signals can be generated by the PWM generator itself, or they can be a vector of external signals connected at the input of the block.

The modulation index(m) of Modulated signal is externally controlled by voltage regulator block.

C: Voltage Regulator

The voltage regulator shown in fig. 7 takes three component of load voltage in per unit(pu) as feedback, applies proper operation to control the modulation index.

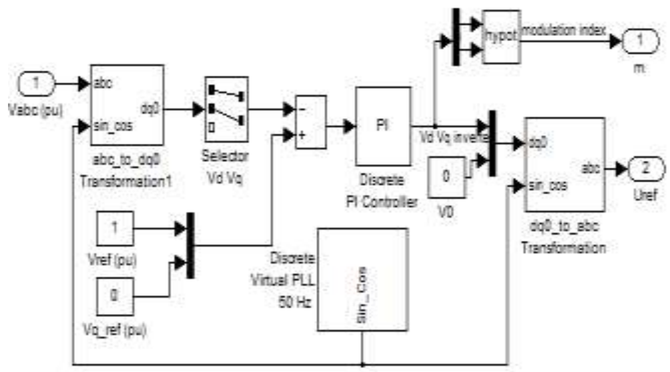

Fig.7: Simulation model of voltage regulator.

D: LC Filter

The primary function of the AC filter is to filter out the high frequency components caused by the inverter switching operation. The LC-filter aims to reduce the high order harmonics which are the multiples of the carrier frequency of PWM generator. The transfer function of the LC-filter designed by the output voltage to the input voltage is given as follows:

$$G(s) = \frac{1}{1 + LC\,s^2} \qquad (6)$$

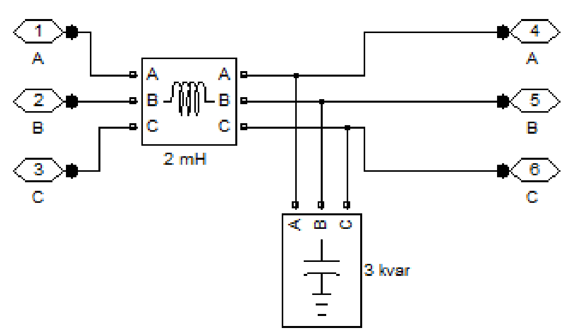

Fig. 8: Simulation model of LC filter.

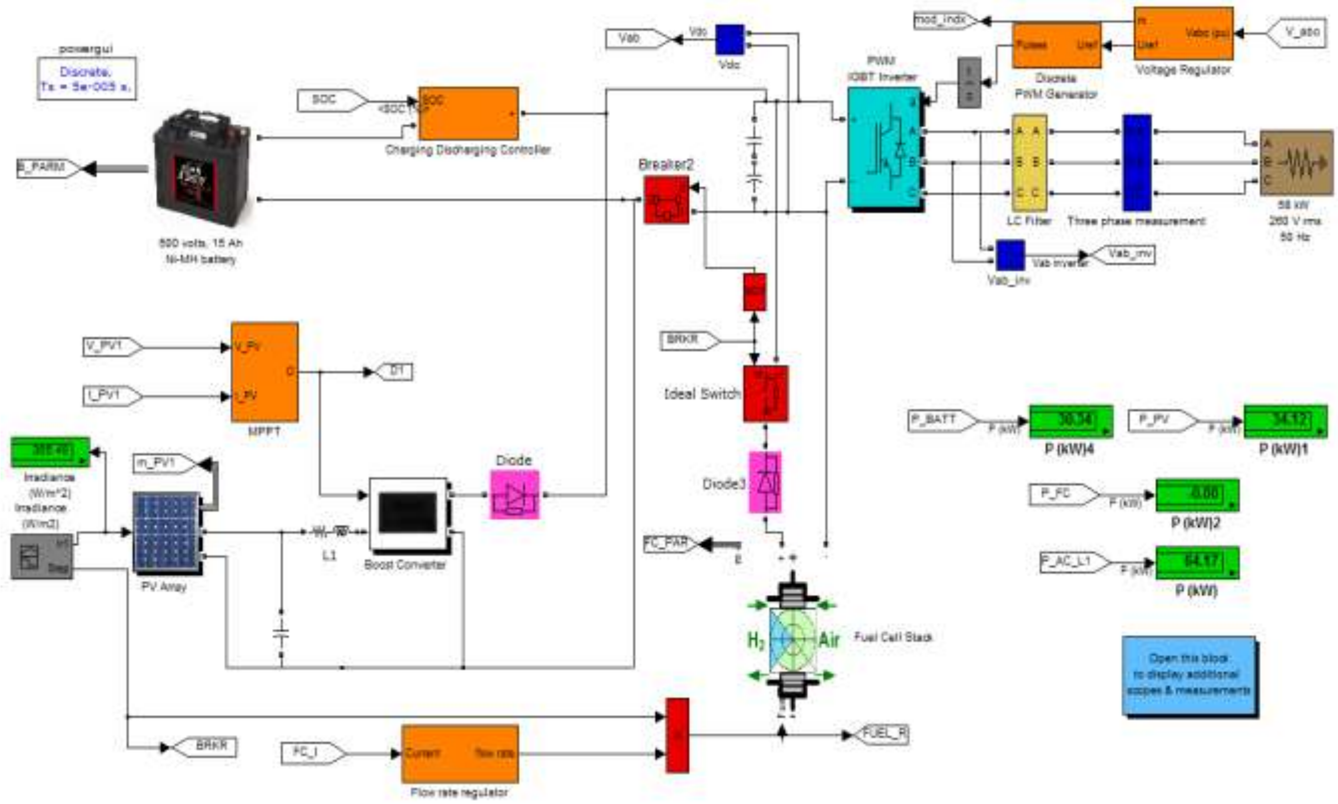

Fig. 9: Simulation model of PVBFC System

IV. SIMULATION PARAMETERS OF COMPONENTS

Table I shows the parameter details of components in proposed PVBFC system.

Table I:

Name of Components	Details about the Component
PVC	Power=100KW , V_o=273.5V at 1000 W/M^2 Irradiance
PEMFC	Power=65KW,V_o=500V
GB	Rated Capacity=15Ah,V_o=500V
MPPT	Tracks Maximum Power Point and Varies duty cycle of Boost Converter
Boost Converter	Boost the V_{mpp} to fixed 500V
FRC	Regulates the fuel flow rate w.r.t fuel cell current
CDC	Control SOC in between 40% to 90%.
PWM IGBT VSI	Convert 500Volt(DC) to 280V(rms) (3-Phase AC)
PWM Generator	3 arm,6 pulse, carrier Frequency=2000KHz
Voltage Regulator	Regulates modulation Index to m=0.875 for PWM Generator
AC Load	V_{rms}=260V,f=50Hz,Power=64kW

V. SIMULATION INPUT AND RESULTS

The PVBFC is simulated over 24s in which the first 12s, battery works in parallel with photovoltaic cell to compensate varying natural conditions in day time and fuel cell works independently at night for the next 12s.

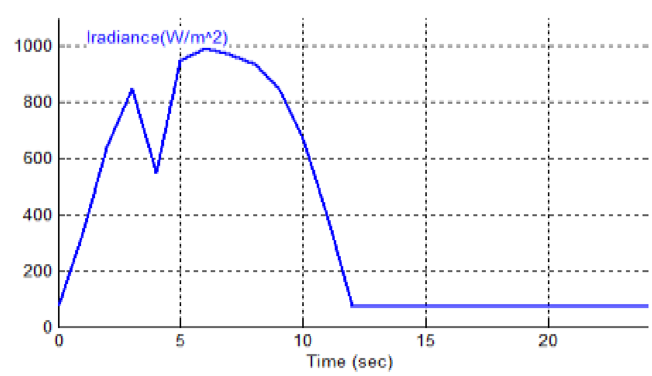

Fig.10: Irradiance versus Time signal with varying natural condition.

A solar irradiance signal is build with the help of signal builder in Matlab considering different natural conditions as shown in Fig.10.

The signal shows following points explained below:

1. Gradual increment in irradiance from t=0s to t=3s considers morning time.
2. Rapid variation in irradiance due to disturbances such as rain, shadow, etc. up to t=5s.
3. Gradual increment and decrement of irradiance from t=5s to t=13s considers afternoon and evening time.
4. Constant irradiance from t=13s to t=24s due to temperature and other light sources at night.

The following lines explain what is going on during the simulation:

1. At t=0s, GB and PVC start working in parallel and, the PEMFC is disabled. Initially SOC is assumed to be 80%. Fig. 11 shows the power(KW) graph of DERs and loads. Since the GB and PVC works in parallel, thereby their power graphs are complementary of each other. Negative power of battery shows that it is being charged by PVC.
2. Natural disturbances as explained in Fig.10 is displayed from t=3s to t=5s.
3. At t=12s, PEMFC is enabled, it begins to provide power alone. And the some power generated by PVC is directly used to charge the GB.
4. Fig.11-18 show the simulation results.
5. Fig. 17 shows the status of battery when it is fully charged at time =8s.

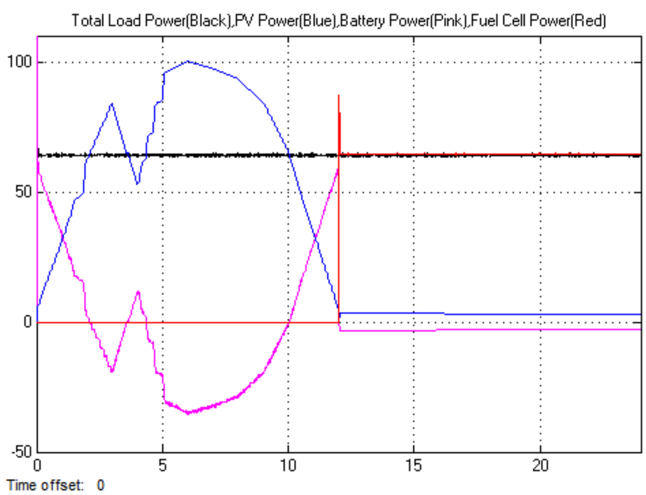

Fig.11: Power(KW) graph.

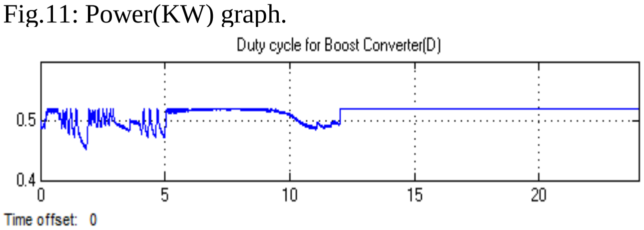

Fig. 11: Duty cycle variation of boost converter.

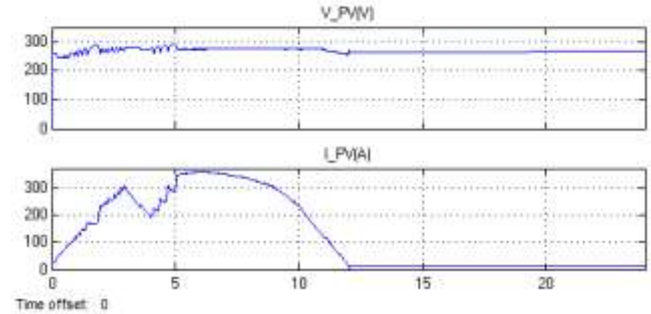

Fig.13: PVC status.

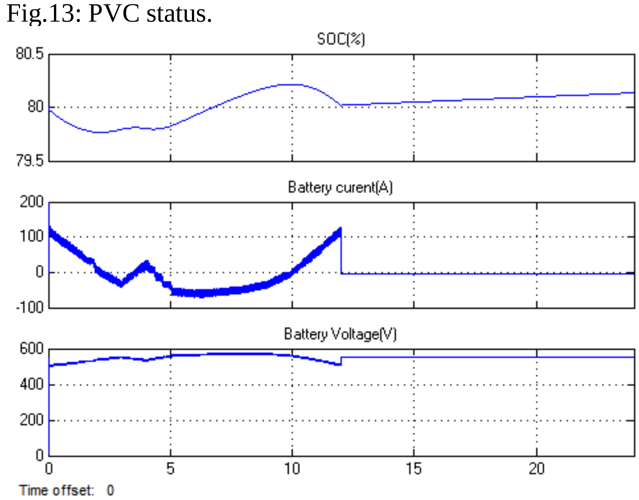

Fig.14: Battery status.

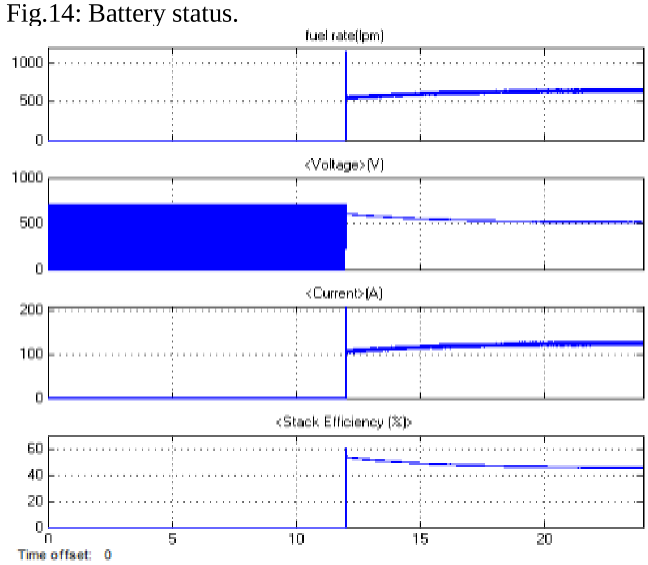

Fig.15: PEMFC status.

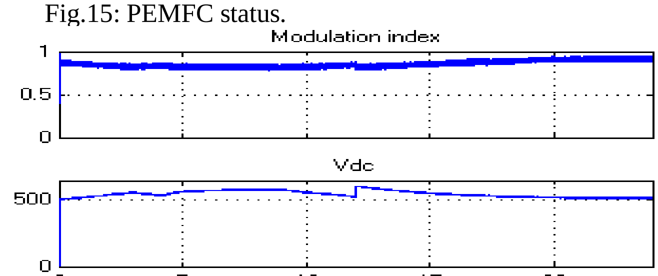

Fig.16: Modulation index of PWM generator and V_{dc} of VSI.

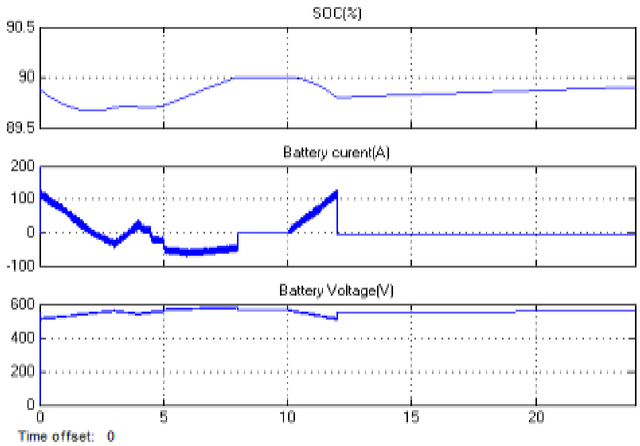

Fig 17: Battery Status when it is fully charged.

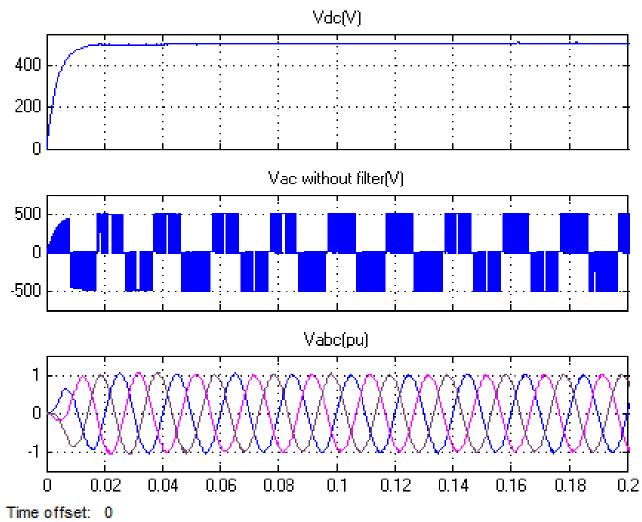

Fig.18:Inverter input V_{dc},Output V_{ac} and load voltage.

VI. CONCLUSION

The modeling and control fraimework of the PVBFC system is developed and simulated in MATLAB/ SIMULINK using SIMPOWER Systems library. The simulation results give encouraging output on the performance of PVBFC integrated system and thus validate the effectiveness of the system. It is useful for further research work such as, maximum power point tracking, integration of PV energy with other energy soucres.

VII. REFERENCES

[1] T. Veziroglu: Hydrogen Energy System: A Permanent Solution to Global Problems, Clean Energy Research Institute, USA, Web Site, visit 2004. http://www.iahe.org

[2] A. A. Chowdhury, S. K. Agarwal, and D. O. Koval, "Reliability modeling of distributed generation in conventional distribution systems planning and analysis," IEEE Transactions on Industry Applications,vl.39, pp. 1493-1498,sept.-oct., 2003.

[3] KJAER, S. B.; et al. A Review of Single-Phase Grid-Connected Inverters for Photovoltaic Modules. IEEE Transactions on Industry Applications, v. 41, n. 5, p.p 1292-1306,2005.

[4] Moacyr A. G. de Brito, Leonardo P. Sampaio, Luigi G. Junior, Carlos A. Canesin: Evaluation of MPPT Techniques for Photovoltaic Applications, IEEE, Brazil,pp.1039-1044, 2011.

[5] Souleman Njoya M., Olivier Tremblay and Louis-A, IEEE Members, A Generic Fuel Cell Model for the Simulation of Fuel Cell Vehicles,pp.1722-1729,2009

[6] Olivier Tremblay, Louis-A. Dessaint, and Abdel-Illah Dekkiche, A Generic Battery Model for the Dynamic Simulation of Hybrid Electric Vehicles. IEEE,p.p 284-289,2007.

[7] Trishan Esram, and Patrick L. Chapman, Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques, IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL.22, NO.2,pp. 439-449,june,2007

[8]Wang NianCHun, ,Wu MeiYue and SHi GuoSHeng, Study on characteristics of photovoltaic cells based on MATLAB simulation, IEEE, 978-1-4244-6255-1,2011

[9]Femia, Giovanni Petrone, Giovanni Spagnuolo, and Massimo Vitelli, Optimization of Perturb and Observe Maximum Power Point Tracking Method Nicola, Member, IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL.20, NO.4, pp. 963-973, JULY 2005.