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Power Management of Grid Connected Renewable Energy Sources

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Abstract — *This paper deals with the closed loop control strategy of grid connected Photovoltaic and PEM fuel cell hybrid system. Paper deals with the 100 KW PV and 16.5 KW PEMFC SR-12 systems. Incremental conductance with proposed algorithm is used for both PV and PEMFC system. Paper also presents the control strategy for control the PEMFC output according to the PV system output. Finally, the whole system is validating through MATLAB – Simulink environment.*

Keywords- *Renewable energy; Photo-Voltaic system; PEM-Fuel Cell; power-management; grid connected; MATLAB*

I. INTRODUCTION

Now a day's increase the energy consumption rate, less availability of fossil fuels and Polluted global environment arise the problems for use more energy sources. As increase the demand of energy, world now move towards the renewable energy sources as alternative energy source. Advantages of renewable energy sources are clean, less polluted, and availability at free of cost. In today, different renewable sources are use as energy source like wind power, solar power, tidal power, geothermal, Hydrogen fuel cell. Out of them solar consider the great energy source as alternative source. But, due to changes the sun irradiation within a day single solar system is not a reliable for supply the power to the load. So, it is necessary to use some other sources with the solar system for feeding constant power to the load as more reliable system [1]-[6].

This paper deal with the solar system and hydrogen PEM fuel cell hybrid system connected with the grid. Here, show the 100 KW PV systems with 16.5KW SR-12 PEMFC as hybrid system. Describe the detail mathematical model of PV and PEM fuel cell with their relevant characteristics. Incremental conductance method is used as MPPT algorithm for both PV and PEMFC systems. Also, present the dynamic model of SR-12 PEMFC module. Discuss the detail control strategy for the grid connected system. The fuel cell output is control using input controllers according to change in PV output. Finally, the different results present with different conditions of grid connected hybrid system using MATLAB/Simulink environment. In fig.1 (a) & (b) present the general overview of grid connected PV-FC hybrid system.

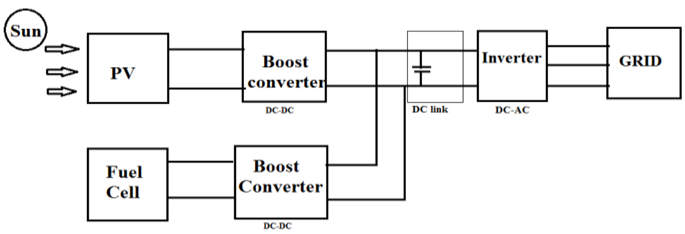

Figure 1 (a) Grid connected hybrid system [3]

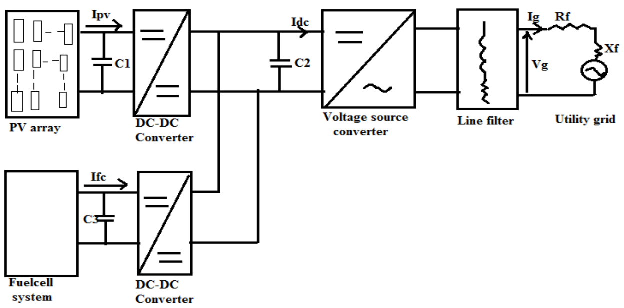

Figure 1 (b) Typical three phase grid connected system [9]

II. BASIC OF PHOTOVOLTAIC SYSTEM

PV system is directly converts the sun energy of light to electrical energy. The basic of about is solar cell. The single solar cell rating is 0.6V. Group of solar cell combine to form module. And different module connected in series-parallel manner to form array. In fig.2 present the basic working of photovoltaic cell. According to the photovoltaic effect sun's irradiation falling to the solar cell, due to electron holes recombination some valence electron become free to move. These electrons are passing through external circuit and produce electrical energy [10].

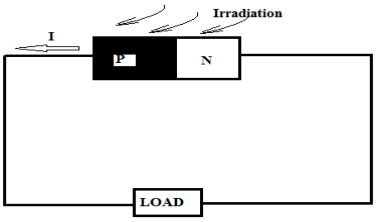

Figure 2 Working of Photovoltaic cell [10]

A. Mathamatical modeling of PV module

In fig, 3 present the mathematical model of solar cell. Here, use the single diode model of solar cell.

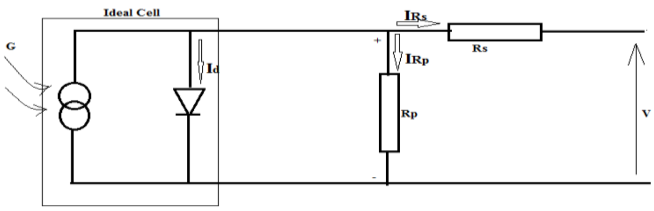

Figure 3 Single diode model of PV cell [11]

Using Kirchoff's law in fig. 3, [11]

$$I_{ph} = I_d + I_{Rp} + I$$

Where,

$$I_d = \frac{I_{ph}}{\left[\exp\left(\frac{qV_{oc}}{N_s AkT}\right) - 1\right]}$$

Photon current is defined by,

$$I_{ph} = [I_{scref} + k_i(T_k - T_{ref})] * \frac{\lambda}{100}$$

Modules reverse saturation current is defined by,

$$I_{rs} = \left(\frac{T}{T_r}\right)^3 \exp\left[\frac{qE_g}{Ak}\left\{\frac{1}{T_r} - \frac{1}{T}\right\}\right]$$

Where,
I_{ph}= Photovoltaic current,
K_i=temperature coefficient,
T_k and T_{ref} = operating temperature and reference temperature in Kelvin respectively
q = electron charge ($1.6*10^{-19}$)
V_{oc} = open circuit voltage,
N_s = No. of cells in series,
K = constant term of Boltzmann,
A= ideality factor of diode,
E_g = band gap energy of semiconductor material

III. BASIC ABOUT FUEL CELL

A hydrogen fuel cell produces the electrical energy by chemical reaction. Every chemical reaction held at electrodes. Fig. 4 presents the working of fuel cell [7].

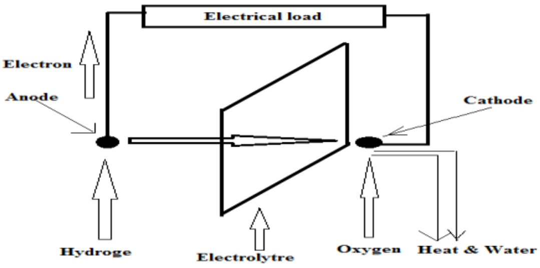

Figure 4 working of fuel cell [7]

Breaking the hydrogen molecules at anode electrons and protons are become free to move. Protons are passing through electrolyte and electrons through electrical circuit. At cathode, none polluted by product water is getting through reaction.

A. Proton exchange membarance fuel cell (PEMFC)

Fig. 5 shows the simple construction of the PEMFC. It is deliver the high power density. It's operating temperature about 80^0 C. due to its lower temperature it's operating quicker and less abrasion on the system units.

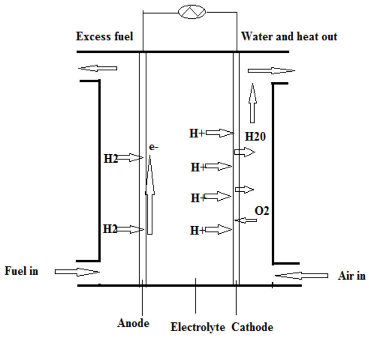

Figure 5 PEMFC [7]

Anodic reaction $$H_2 \rightarrow 2H^+ + 2e$$

Cathode reaction $$\frac{1}{2}O_2 + 2H^+ + 2e \rightarrow H_2$$

Overall reaction $$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

B. *Mathamatical modeling of PEMFC*

In fig. 6 represent the electrical circuit of PEMFC. The fuel cell voltage is given by, [7]

$$V_{Fc} = E_{nernst} - V_{act} - V_{ohmic} - V_{con}$$

The output voltage of n stack is given by,

$$V_{stack} = n * V_{Fuel\ cell}$$

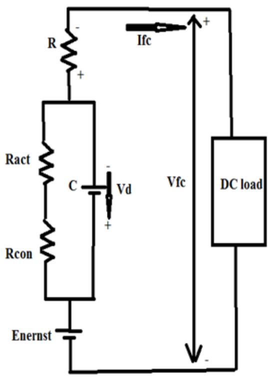

Figure 6 Electrical equivalent circuit of PEMFC [7]

Pressure of H_2 and o_2 is given by [12],

$$P_{H_2} = 0.5 * P_{H_2o}{}^{sat}[\frac{P_a}{P_{H_2oS}\exp\left(\frac{1.653J}{T1.334}\right)} - 1]$$

$$P_{o2} = P_{H20}{}^{sat}[\frac{P_c}{P_{H2o}{}^{sat}\exp\left(\frac{4.192J}{T^{1.334}}\right)} - 1]$$

$$V_{act1} = [\eta_0 + (T - 298)a$$

$$V_{act2} = [T.bln(I)]$$

$$V_{ohm} = i * R_{ohm}$$

$$V_{conc} = \frac{RT}{ZF}\ln(1 - \frac{i}{i_{limit}})$$

Consider double layer charging effect,

$$V_c = \left(1 - C\frac{dV_c}{dt}\right)(R_{act} + R_{conc})$$

So, output voltage defined as,

$$V_{out} = E - V_{act1} - V_c - V_{ohm}$$

IV. BASIC ABOUT BOOST CONVERTER AND MPPT

A. Boost converter

The boost converter is providing the output voltage greater than input voltage. That is the reason; it is also called as step-up converter. The simple circuit of boost converter is shown in fig. 7 [8].

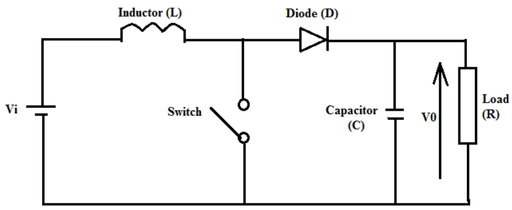

Figure 7 Boost converter [8]

The relationship between input and output voltage for boost converter is, [8]

$$\frac{1}{L}\int_0^{T_{on}} (V_i)dt + \frac{1}{L}\int_0^{T_{off}} (V_i - V_0)dt = 0$$

Reduce equation,

$$\frac{V_0}{V_i} = \frac{1}{1-d}$$

B. Maximum power point tracking algorithem (MPPT)

The maximum power occurs at the knee point of the I-V characteristic. MPPT algorithm only searches the maximum power point at different instant and according to that point changes the duty cycle of DC-DC converter (here boost converter) for control the switching instants. Different MPPT algorithm is use for tracking MPP like constant voltage, Perturb and observation, sampling method, seeking algorithm, artificial intelligent method, open circuit voltage, short circuit current and incremental conductance method. In this study use the incremental conductance method with integral regulator as MPPT algorithm for both PV and fuel cell system. Fig. 8 shows the flow chart for incremental conductance MPPT algorithm [13].

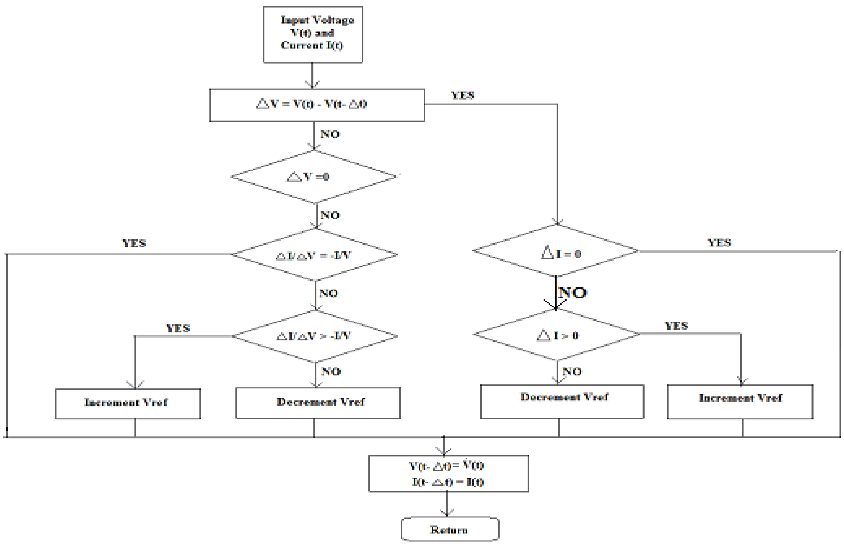

Figure 8 Flow chart of incremental conductance algorithm [13]

C. Proposed MPPT algorithm

The incremental conductance algorithm uses the derivative of the conductance for finding the MPP operating point of the system. In this proposed algorithm integral regulator is include for reduce the error $(\frac{\partial I}{\partial V}+\frac{I}{V})$. The regulator output is equal to the duty cycle correction. The MPP is obtaining when $\frac{\partial I}{\partial V}=0$. Fig. 9 presents the proposed MPPT algorithm for this system [13].

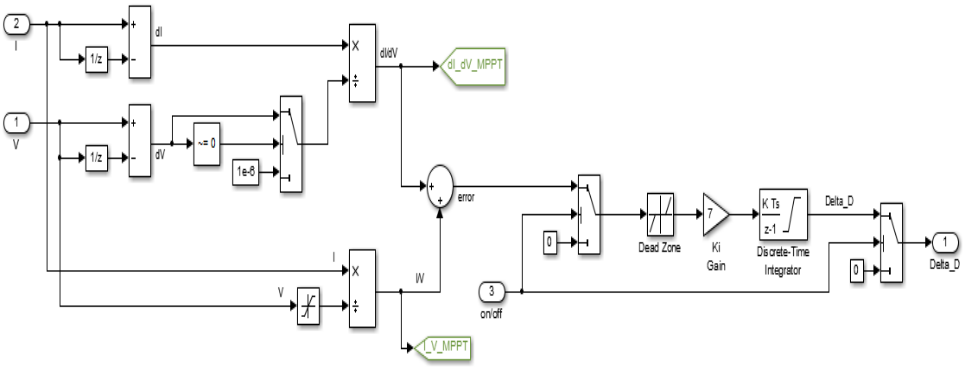

Figure 9 proposed algorithm MPPT [13]

V. BRIEF DESCRIPTION ABOUT THE GRID CONNECTED SYSTEM

This paper present the grid connected PV-FC system with their control strategy for controlling the power. Here, deal with the 100 KW PV systems with 16.5 KW PEMFC.

A. Grid synchronisation with VSC control stretergy

The grid side inverter is controlled by three phase Voltage source converter. This is converted the 500V Vdc to 260Vac. The control strategy applied to the voltage source converter consists of two control loops. Internal control loop for grid synchronism and external control loop for controlling the DC voltage. The typical control strategy for this system is present in fig. 10 [9], [16], [18], [19], [20].

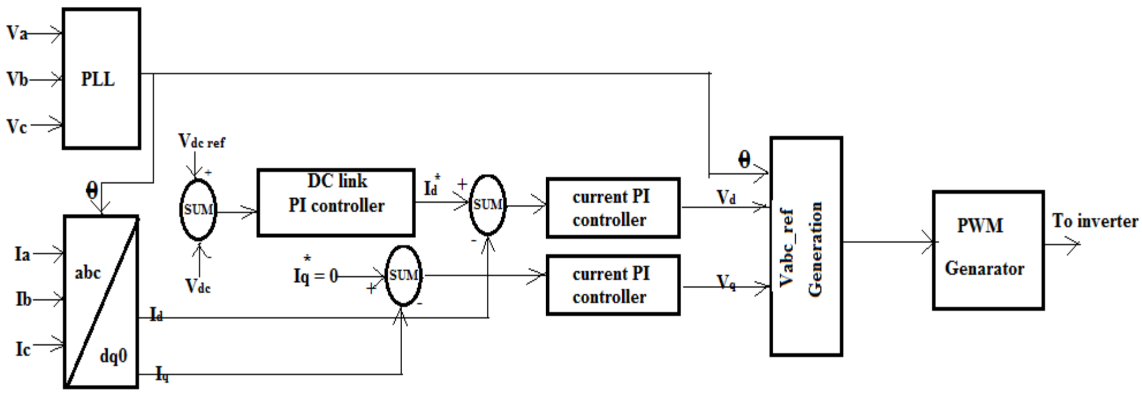

Figure 10 Typical control strategies for VSC control [9]

B. DC voltage controller

The DC voltage controller regulates the voltage upto 500V. in fig. 10 sows the d DC voltage regulator in control stretergy of VSC. This DC bus voltage regulator regulates the desired active power. As in fig. 10 the output of the DC controller is the input of active current controller [9], [16], [18], [19], [20].

C. Internal control loop

Grid voltage and current are transformed to the rotating synchronously reference frame (d-q control). The d-q control is also shown in fig. 10. By using synchronous frame, the all variables are transformed to DC values. Hence, easily design controller and filter for the system. Here, the phase looked loop (PLL) is used for extracting the phase angle from the grid voltage. This extracted phase angle is used for synchronize the grid current to the grid voltage. In synchronous reference frame the reactive current I_q is set to zero for maintain the unity power factor and reference for active current I_d (the output of the DC voltage controller). Fig. 7 represent the detail control strategy of grid connected PV-FC system with control the fuel cell output according to PV output [9], [16], [18], [19], [20].

D. Fuel cell output control

In this fuel cell control strategy, the output of fuel cell is control by current controller as well as pressure controller schemes. In current controller scheme, according to change the PV output current the input of fuel cell current will be change. In pressure control scheme, change in power of the grid is taken into account and according to that change the pressure of the anode at input of fuel cell will be control. Hence, the output of fuel cell will be controlled with change in energy demand.

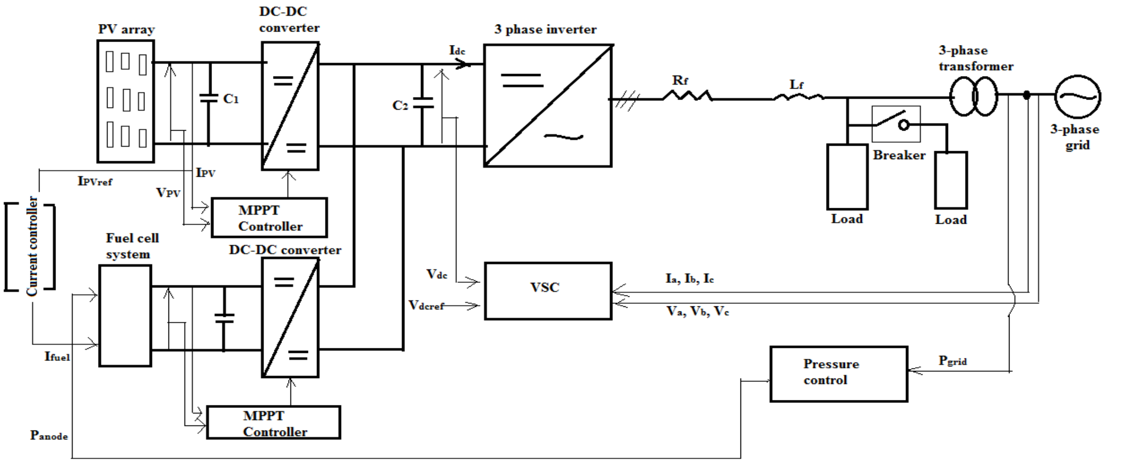

Figure 11 Typical grid connected PV-FC system

VI. SIMULATION RESULTS AND DISCUSSION

In fig. 12-(a), (b) shows the simulation characteristics of 36 W PV modules.

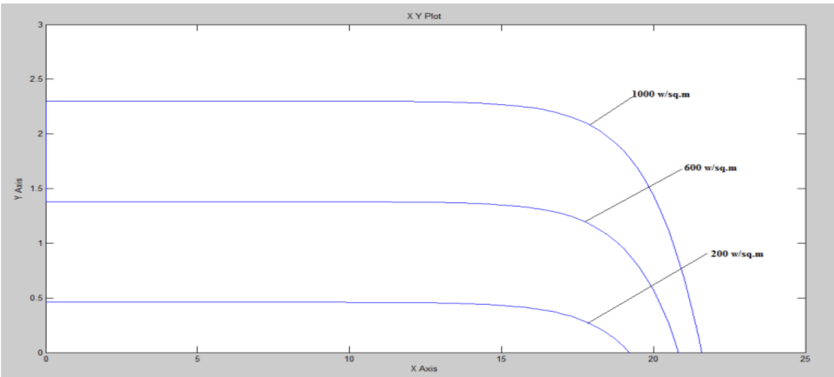

Figure 12 - (a) I-V characteristic of PV module with varying irradiation [11]

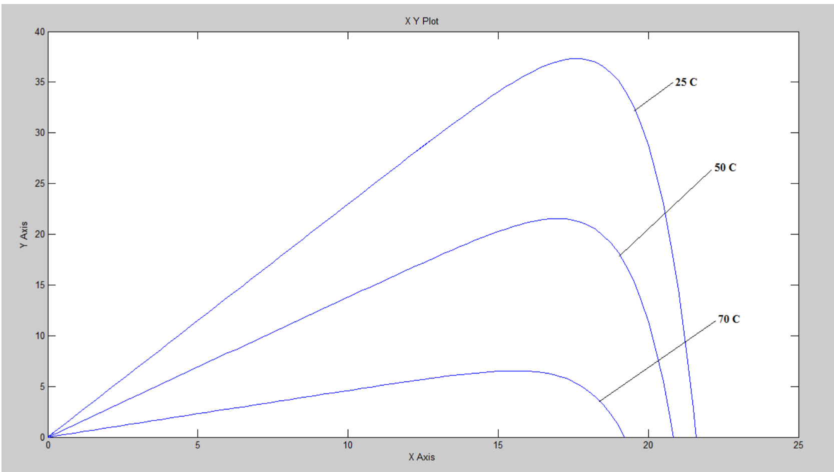

Figure 12 - (b) P-V characteristic of PV module [11]

In fig. 13-(a), (b) show the I-V and dynamic response of 500 W PEMFC SR-12 module.

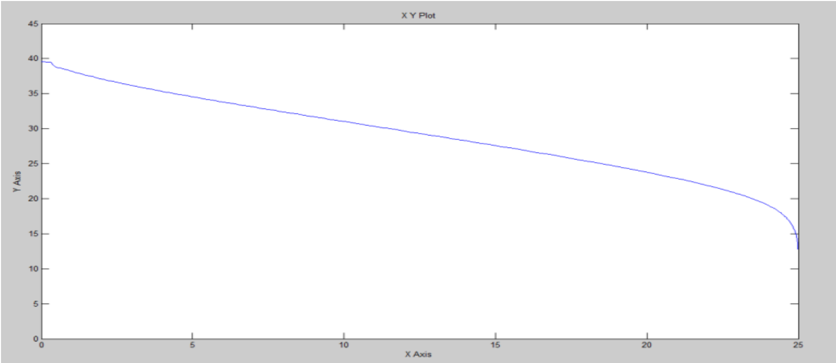

Figure 13 - (a) I-V characteristic of PEMFC SR-12 module [7]

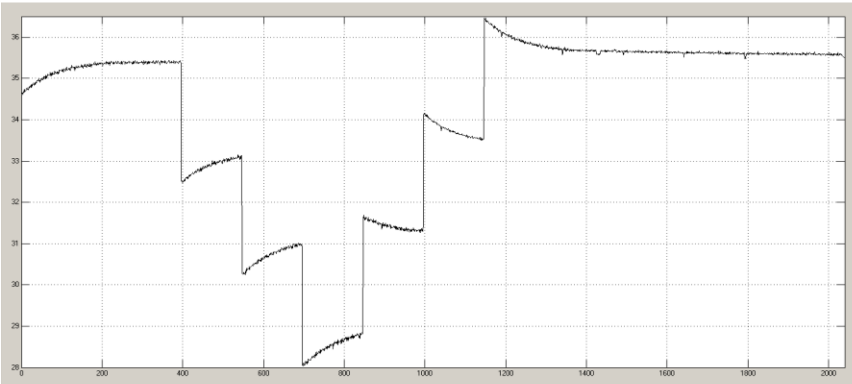

Figure 14 - (c) Voltage under dynamic condition of PEMFC [7]

PV-FC HYBRID SYSTEM WITH INPUT CONTROLLERS

In fig. 15-(a) shows the grid connected PV-FC system with input controllers for fuel cell output control. Here, for current controller the PV input current is taking as a reference and according to that the input current of the fuel cell will be change. For pressure control, the anode pressure is varying according to the change in grid power. Here, sun radiation taking as variable 1000 W/m2, 850 W/m2 and 750 W/m2. Hence, the output power is change according to change with power demand. The excess power is given to the grid which is shown in fig. 15-(b). The three phase grid voltage, three phase grid current and voltage of VSC (Vab VSC) are shown in fig. 15-(c), 15-(d), 15-(e). The fig. 15-(f) presents the output Vdc of boost converter and modulation index.

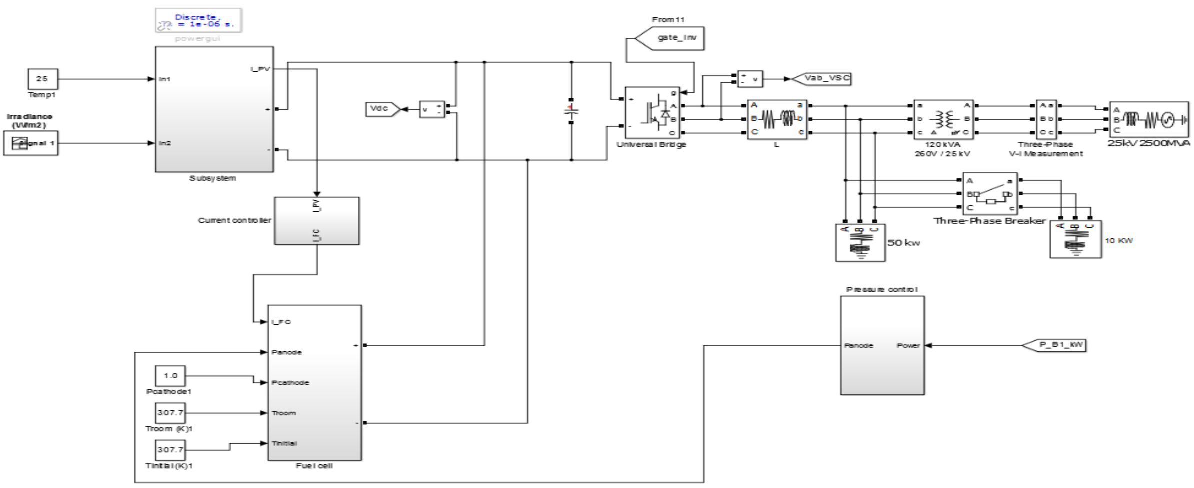

Figure 14 - (a) PV - FC hybrid system with input controllers

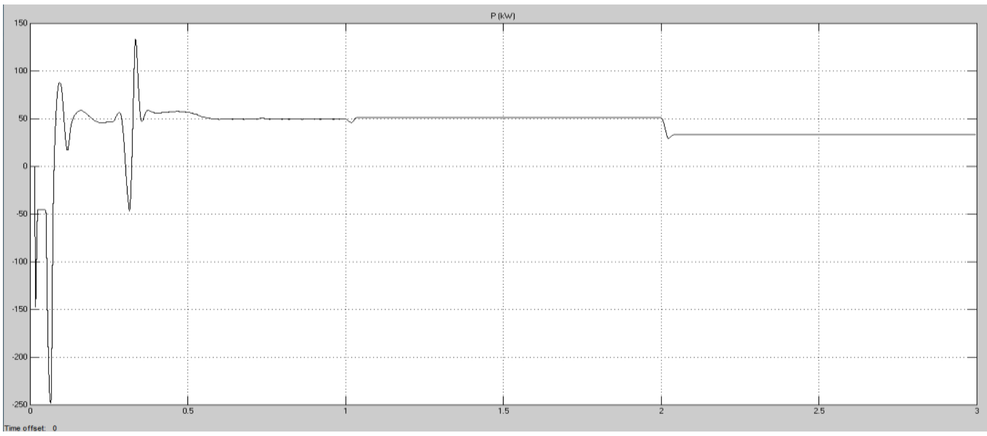

Figure 15 – (b) Grid power

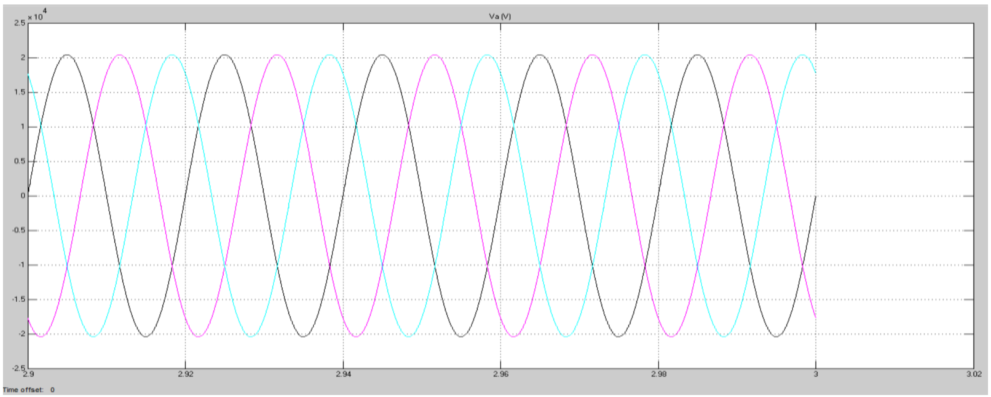

Figure 15 – (c) three phase grid voltage

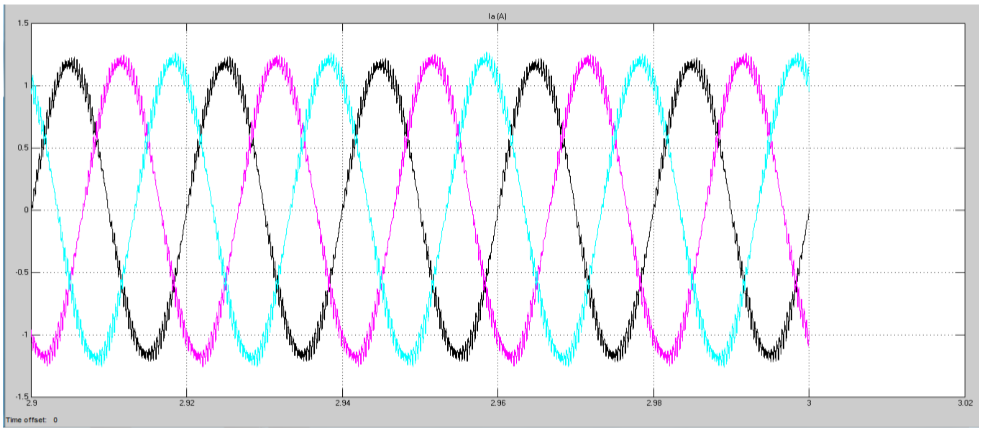

Figure 15 – (d) three phase grid current

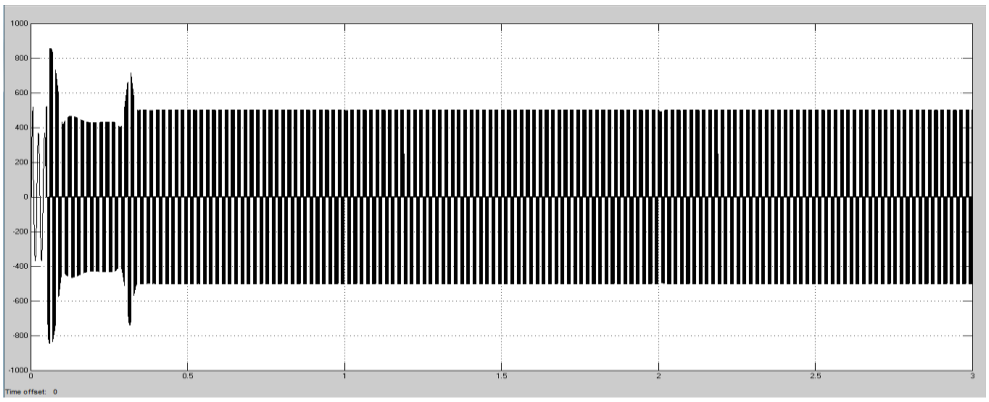

Figure 15 – (e) Vab VSC

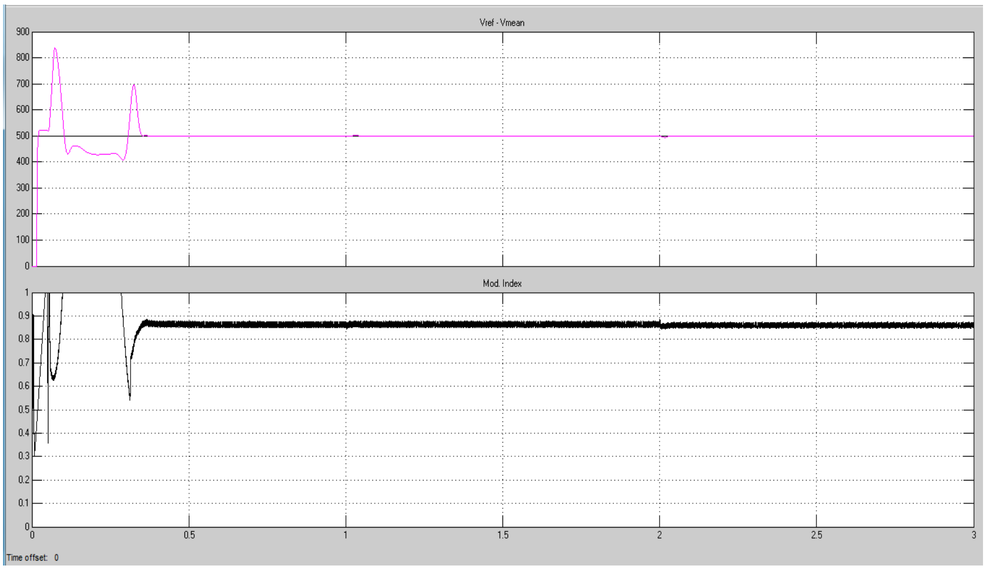

Figure 15 – (f) output Vdc boost of PV array and modulation index

Table 1 Summarize the results

Time	Sun's radiation	Power generated by PV	Power generated by FC	Load connected	Power supply to the grid
[0 1]	1000 W/m^2	99.64 KW	1.2 KW	50 KW	50.84 KW
[1 2]	850 W/m^2	84.58 KW	16.33 KW	50 KW	50.91 KW
[2 3]	750 W/m^2	75.61 KW	16.47 KW	60 KW	32.08 KW

VII. CONCLUSION AND FUTURE WORK

This work presents the closed loop control strategy for grid connected PV-FC hybrid system. By using VSC controller flexible control can be achieve and system become more reliable. With the input current controller, output of the fuel cell system to be control according to the PV output. Hence, hybrid system generation is also to be under control.

In future, we will also use the other renewable generation sources with the system for more generation and will also evaluate the different control schemes for more flexible and reliable control system.

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APPENDIX

Rated power	37.08W
Voltage at max. power (V_{mp})	16.56V
Current at max. power (I_{mp})	2.25 A
Open circuit voltage (V_{oc})	21.24 V
Short circuit current (I_{scr})	2.55 A
Series solar cell (N_s)	36
Parallel solar cell (N_p)	1

Description	Value
Capacity	500W
Number of Cells	48
Operating Environmental Temperature	5-35° C
Operating Pressures	P_{H2} = 1.5 atm, $P_{cathode}$ = 1.0 atm
Unit Dimensions (W*D*H)	56.5 cm*61.5 cm* 34.5 cm
Weight	44kg

