Power Management of PV and Fuel Cells Connected to Grid

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***Abstract*—This paper deals with those closed loop control method about grid connected photovoltaic and PEM fuel cell hybrid system. Paper bargains for those 100 kw PV and 16. 5 kw PEMFC SR-12 frameworks. Incremental conductance for recommended algorithm will be utilized for both PV Also PEMFC system. Paper also displays the control method for control the PEMFC output according to the PV system output. Finally, the entirety system is accepting through MATLAB – Simulink environment.**

***Index Terms*— Renewable energy; Photo-Voltaic system; PEM-Fuel Cell; Power-Management; grid connected; MATLAB**

I. INTRODUCTION

Currently a day's expand those Vitality utilization rate, lesquerella accessibility for fossil fills What's more dirtied worldwide nature's domain emerge those issues to use additional vitality sources. Likewise expansion the interest about energy, globe currently move towards those renewable vitality sources Concerning illustration elective vitality hotspot. Preferences of renewable vitality sources would clean, lesquerella polluted, Also accessibility at free of cosset. On today, different renewable sources are utilization as vitality wellspring similar to wind power, sun based power, tidal power, geothermal, hydrogen power module. Crazy for them sun based think about the great vitality hotspot Likewise elective wellspring. But, because of transforms the sun illumination inside An day absolute earth's planetary group is not An dependable to supply those force of the load. So, it is essential to utilize some other wellsprings for those earth's planetary group to nourishing steady force of the load Likewise a greater amount dependable framework. [1]-[6].

This paper manage those earth's planetary group Also hydrogen PEM fuel cell hybrid system connected with the grid. Here, demonstrate the 100 kw PV frameworks with 16. 5KW SR-12 PEMFC as hybrid system. Depict those point of interest scientific model from claiming PV What's more PEM power module with their important aspects. Incremental conductance system is utilized Similarly as MPPT algorithm to both PV and PEMFC module. Also, available those changing model of SR-12 PEMFC module. Examine the point of interest control method to the grid joined framework. Those power module yield will be control utilizing enter controllers as stated by progress Previously, PV yield. Finally, the distinctive outcomes introduce with different states for grid joined mixture framework utilizing MATLAB/Simulink surroundings. Done fig. 1 (a) & (b) display the general diagram from claiming grid associated PV-FC hybrid system.

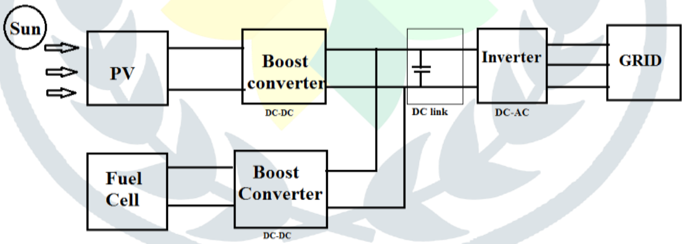

Figure 1 (a) Grid connected hybrid system [3]

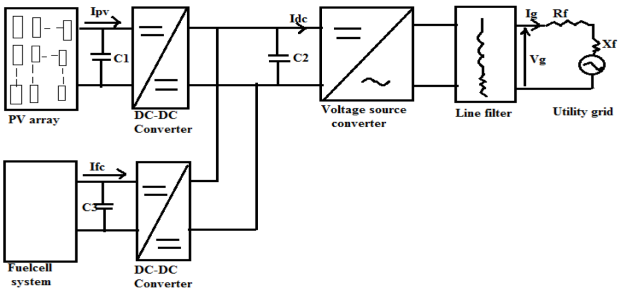

Figure 1 (b) Typical three phase grid connected system [9]

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].

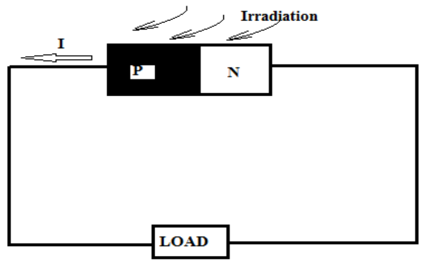

Figure 2 Working of Photovoltaic cell [10]

Mathematical modeling of PV module

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

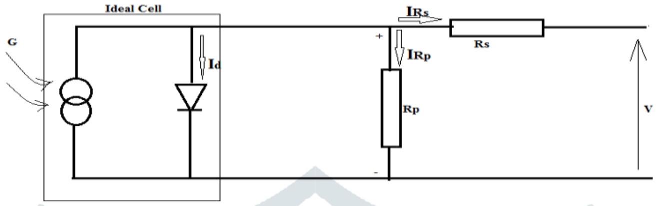

Figure 3 Single diode model of PV cell [11]

Using Kirchhoff'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].

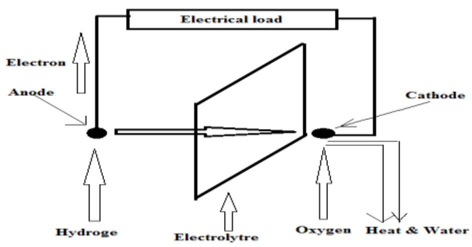

Figure 4 working of fuel cell [7]

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.

Proton exchange membarance fuel cell (PEMFC)

In Figure 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.

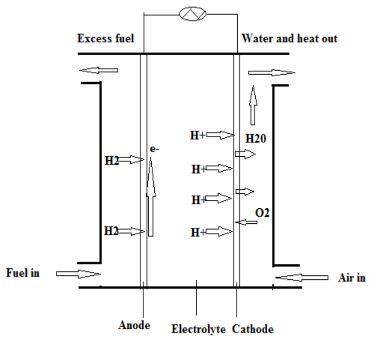

Figure 5 PEMFC [7]

Anodic reaction

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

Cathode reaction

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

Overall reaction

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

Mathematical modeling of PEMFC

In figure 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,

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

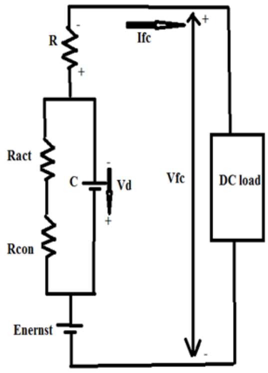

Figure 6 Electrical equivalent circuit of PEMFC [7]

Pressure of H_2 and O_2 is given by [12],

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

$$P_{o2} = P_{H2O}{}^{sat}\left[\frac{P_c}{P_{H2o}{}^{sat}\exp\left(\frac{4.192J}{T^{1.334}}\right)} - 1\right]$$

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

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

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

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

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

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].

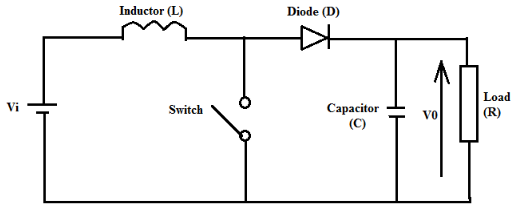

Figure 7 Boost converter [8]

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,

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

Maximum power point tracking algorithm (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].

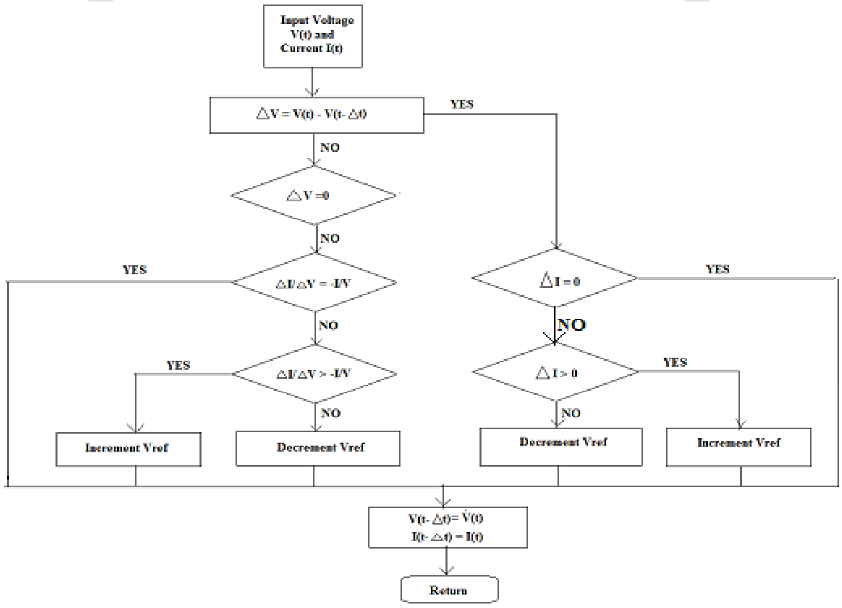

Figure 8 Flow chart of incremental conductance algorithm [13]

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].

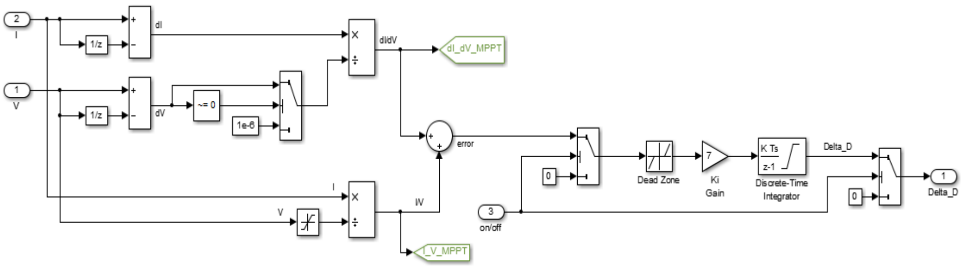

Figure 9 proposed algorithm MPPT [13]

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.

Grid synchronization with VSC control strategy

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].

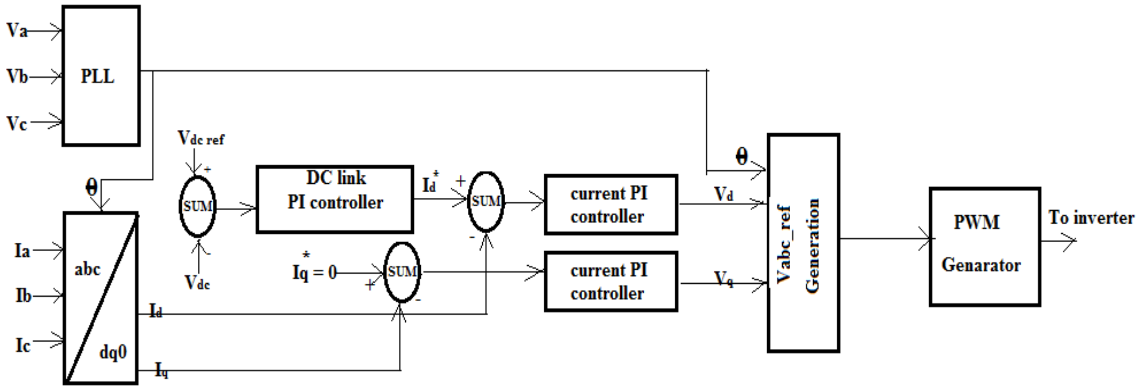

Figure 10 Typical control strategies for VSC control [9]

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].

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].

Fuel cell output control

Here, use one more strategy for control the output of fuel cell according to PV generation. As shown in fig. 11, current controller is used for supply the input to the fuel cell. Here, simple strategy is used for controlled the input current of fuel cell as control the output of fuel cell generation.

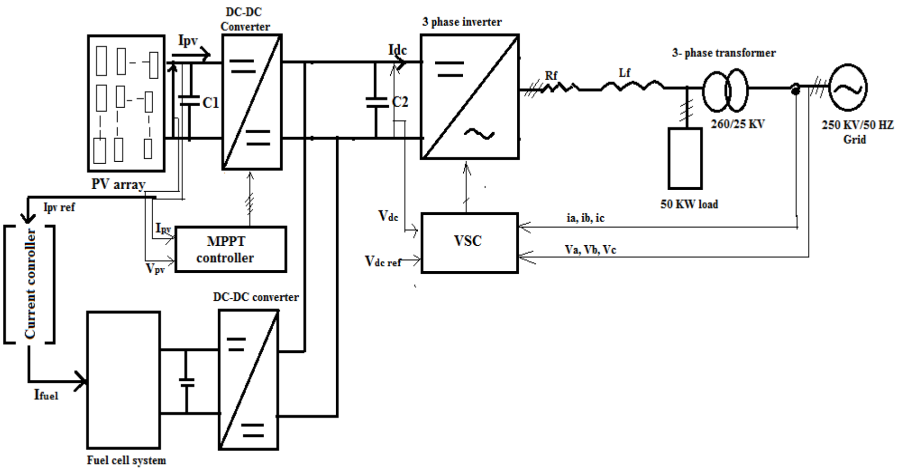

Figure 11 Typical grid connected PV-FC system

VI. SIMULATION RESULTS AND DISCUSSION

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

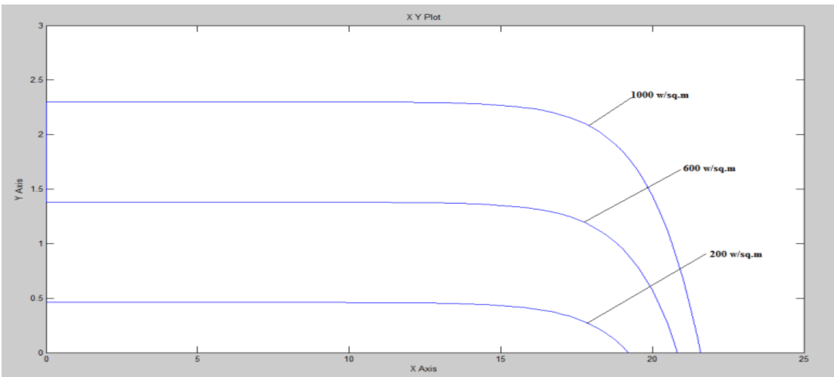

Figure 12 - (a) I-V characteristic of PV module with varying irradiation [11]

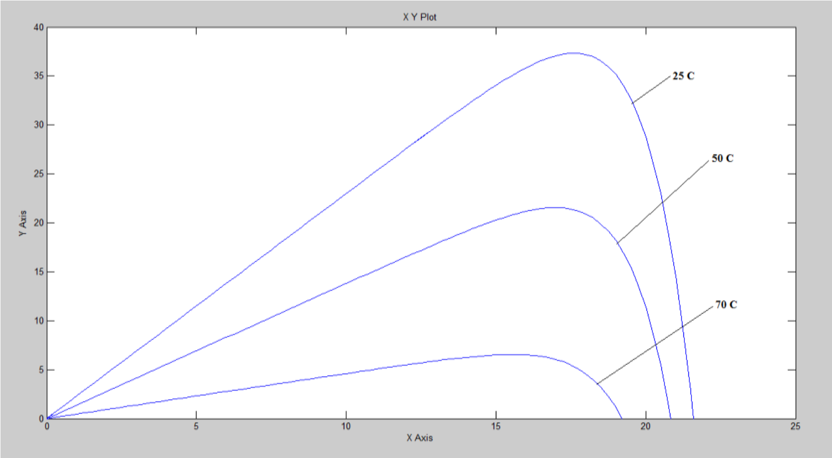

Figure 12 - (b) P-V characteristic of PV module [11]

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

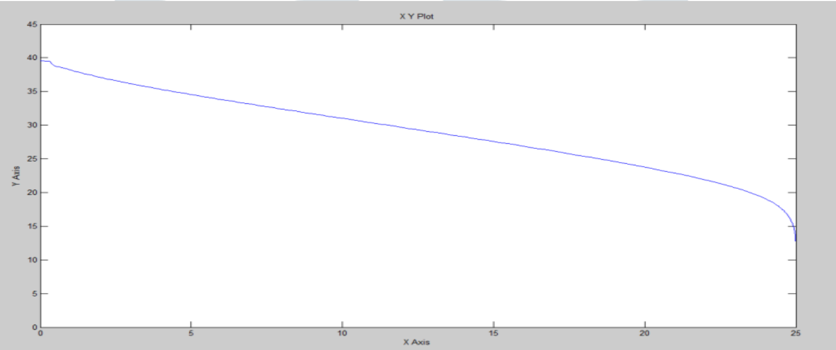

Figure 13 - (a) I-V characteristic of PEMFC SR-12 module [7]

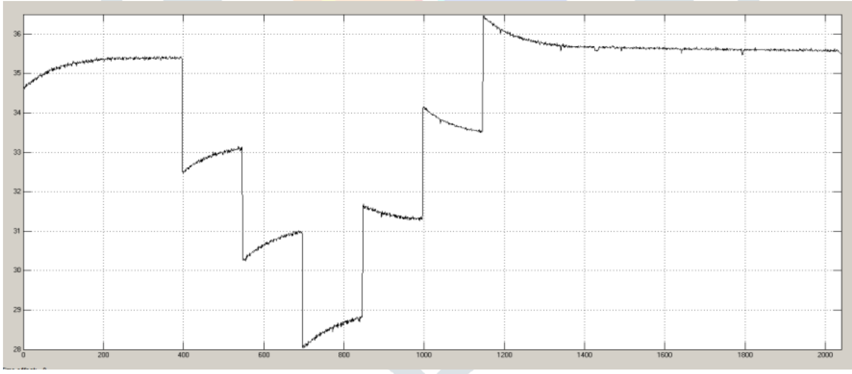

Figure 13 - (b) Voltage under dynamic condition of PEMFC [7]

PV-FC Hybrid system with input controller

In fig. 14-(a) present the results for PV-FC hybrid system with fuel cell output control. Here, taking the sun irradiation variable as 850 W/m^2 to 1000 W/m^2. Here, by using current controller approximately constant power 100 KW gain through PV-FC hybrid system (50 KW supply to the load and 50 KW excess power supply to the grid). After 1.5 s in system, sun irradiation is increase to 1000 W/m^2 from 850 W/m^2. The fuel cell input current increase to feed few kilowatt supplies.

At sun radiation 850 W/m^2 the PV system generate the 86.5 KW. At that time normal fuel current input to the fuel cell by ramp input to generate the output 16.5 KW. So the net output generate of the hybrid system is 103 KW. And, at t=1.5s, the sun radiation change to 1000 W/m^2. As described in above at 1000 W/m^2, PV generation is near up to 100 KW. So, increase the input current of fuel cell for few kilowatt generations. The demerit of this control strategy is that the internal loss occurs in fuel cell due to internal resistance. But, here consider this control scheme for feed the constant power.

In figure 14-(b), present the excess grid power approximate 50 KW supply to the grid. As shown in figure after the 1.5s grid power is disturbed for few seconds. But, it again takes steady value near up to 50 KW. Fig. 14.-(c) presents the three phase grid voltage and current and also presents the single phase voltage and current in 14-(d). In fig. 14 - (e) show the boost output of PV side with approximate 500 V DC and graph of modulation index. In fig. 14 – (f) present the boost output of fuel cell with approximately 500 V. In fig. 14 – (g) present the single phase (V_{ab}) voltage of VSC.

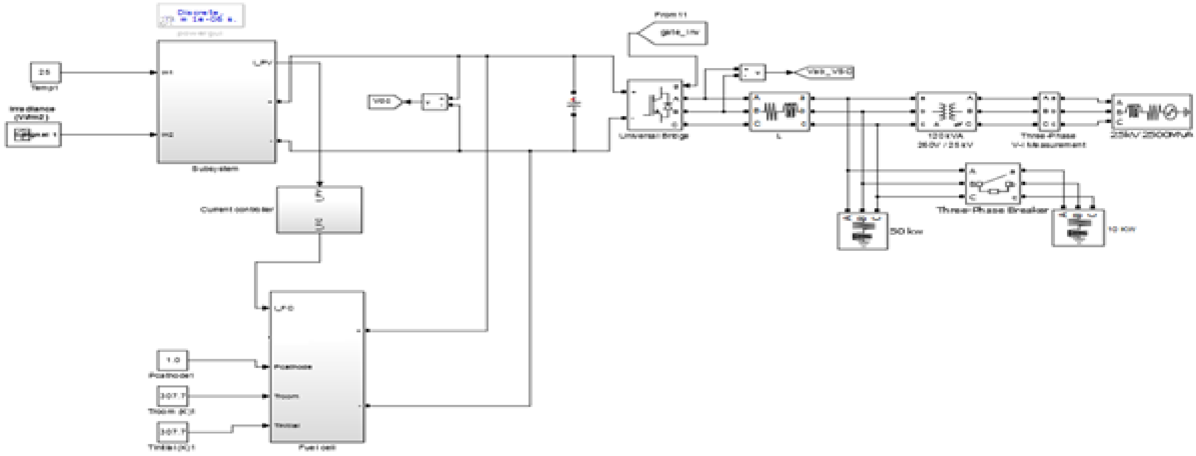

Figure 14 - (a) PV - FC hybrid system with input controllers

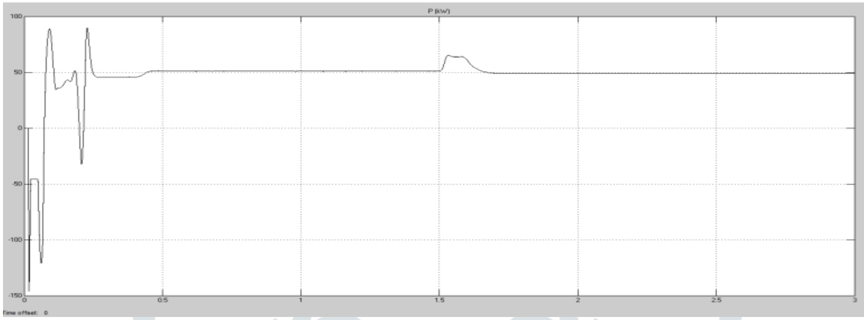

Figure 14 – (b) Grid power

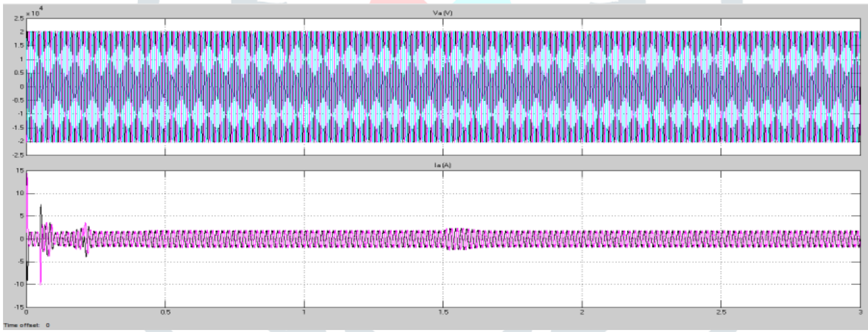

Figure 14 – (c) Three Phase Grid Voltage

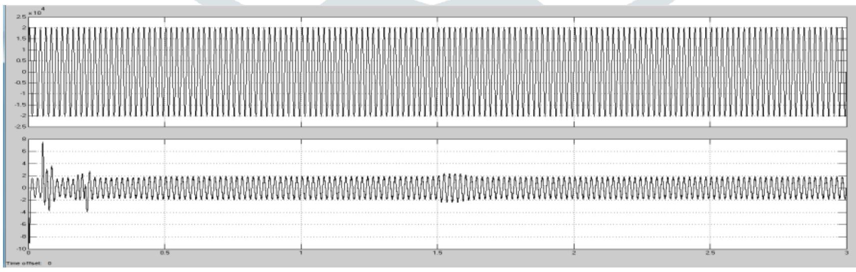

Figure 14 – (d) Vab and Iab of grid

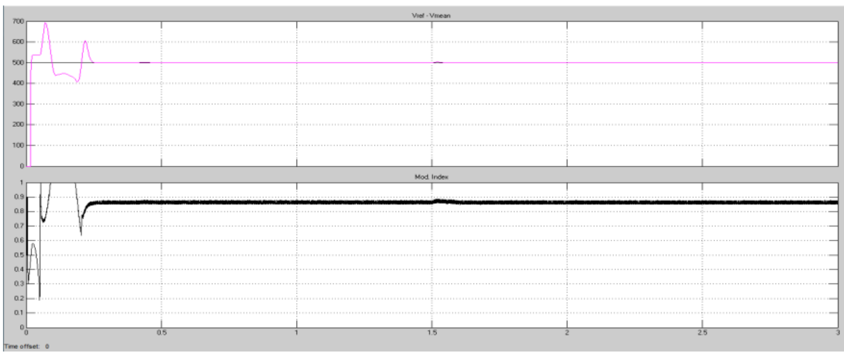

Figure 14 – (e) Vab VSC

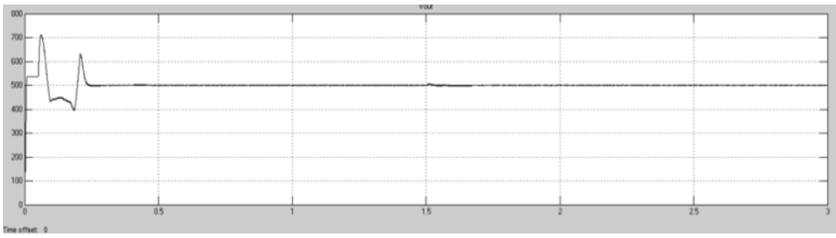

Figure 14 – (f) output Vdc boost of PV array and modulation index

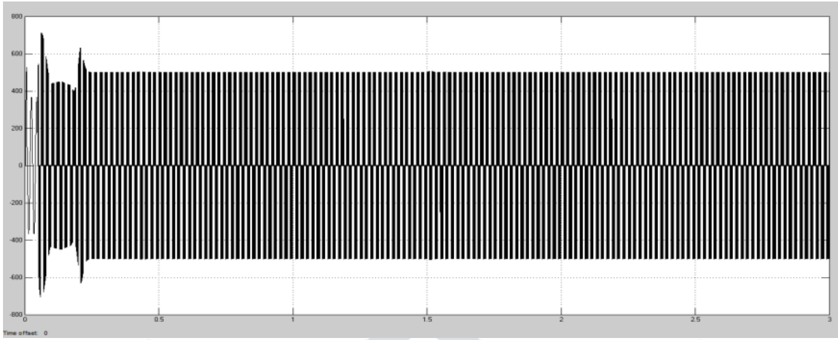

Figure 14-(g) Voltage Vab VSC

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	500 W
Number of Cells	48
Operating Environmental Temperature	5-35° C
Operating Pressures	2 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