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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 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. 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.

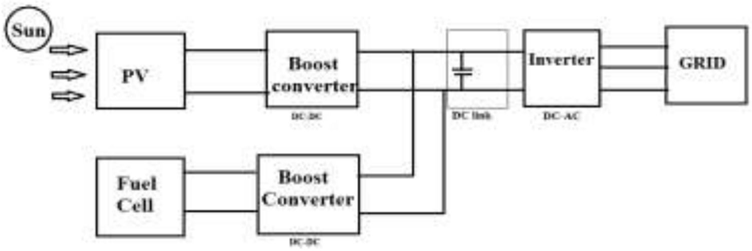

Figure 1 (a) Grid connected hybrid system [3]

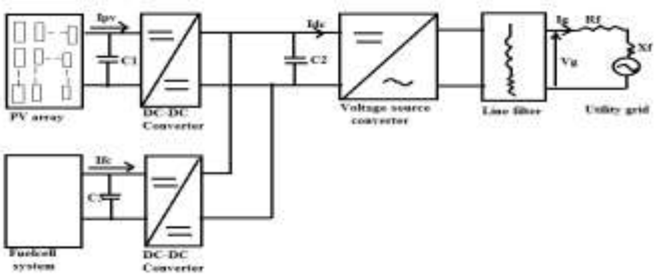

Figure 1 (b) Typical three phase grid connected system [9]

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].

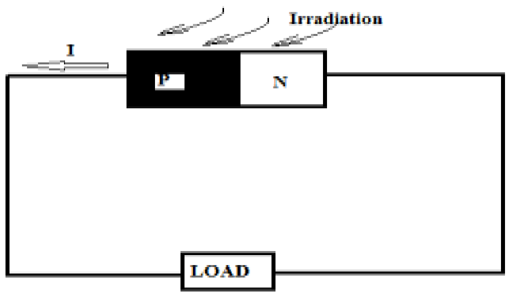

Figure 2 Working of Photovoltaic cell [10]

A. Mathematical modelling of PV module

In fig. (3) Present the mathematical model of solar cell. Here, use the single diode model of solar cell.

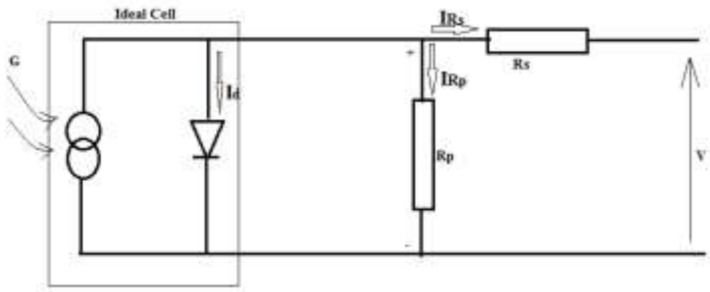

Figure 3 Single diode model of PV cell [11]

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

Where,

...... (1)

..... (2)

Photon current is defined by,

Modules reverse saturation current is defined by,

..... (3)

..... (4)

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].

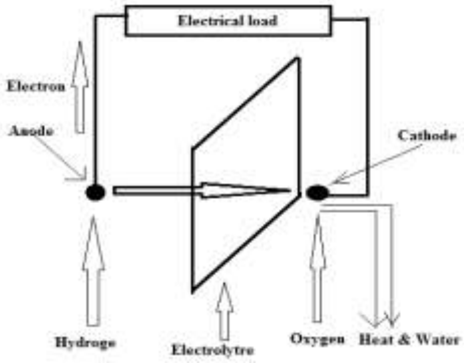

Figure 4 working of fuel cell [7]

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 Membrane Fuel Cell

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.

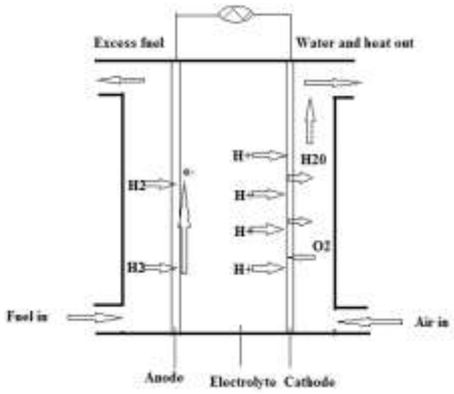

Figure 5 PEMFC [7]

Anodic reaction …. (5)

Cathode reaction …. (6)

Overall reaction …. (7) –

B. Mathematical Model of PEMFC

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

…. (8)

The output voltage of n stack is given by,

…. (9)

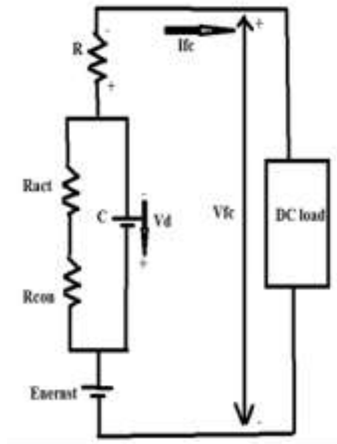

Figure 6 Electrical equivalent circuit of PEMFC [7] Pressure of H_2 and o_2 is given by [12],

…. (10)

…. (11)

…. (12)

…. (13)

…. (14)

…. (15)

Consider double layer charging effect,
So, output voltage defined as,

IV. Basic About Boost Converter And Mppt

A. Boost Converter

…. (16)
….. (17)

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].

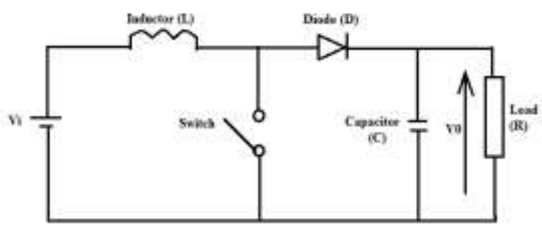

Figure 7 Boost converter [8]

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

Reduce equation,
…. (18)
….. (19)

B. Maximum Power Point Tracking Algorithm

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].

C. Proposed MPPT algorithm

The incremental conductance method uses the derivative of the conductance for finding the MPP operating point of the system. In the proposed algorithm integral regulator is include for reduce the error. The regulator output is equal to the duty cycle correction. The MPP is obtaining when. Fig. 9 presents the proposed MPPT algorithm for this system. [13]

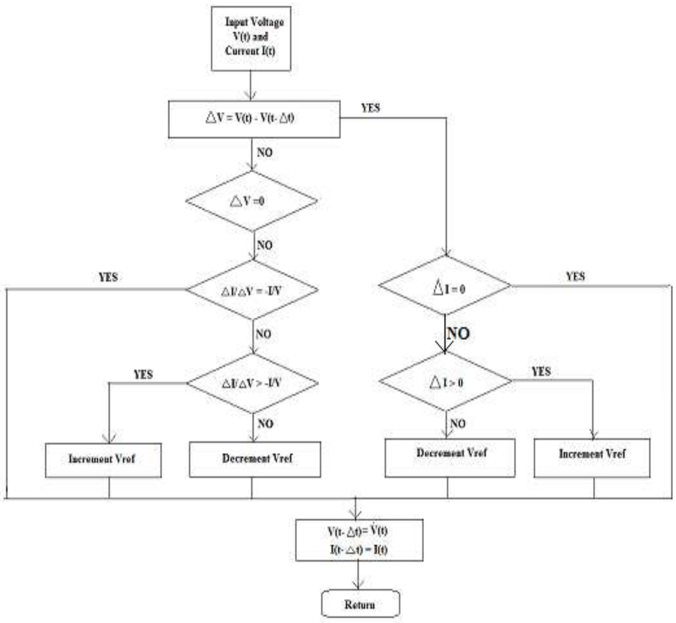

Figure 8 Flow chart of incremental conductance algorithm [13]

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.

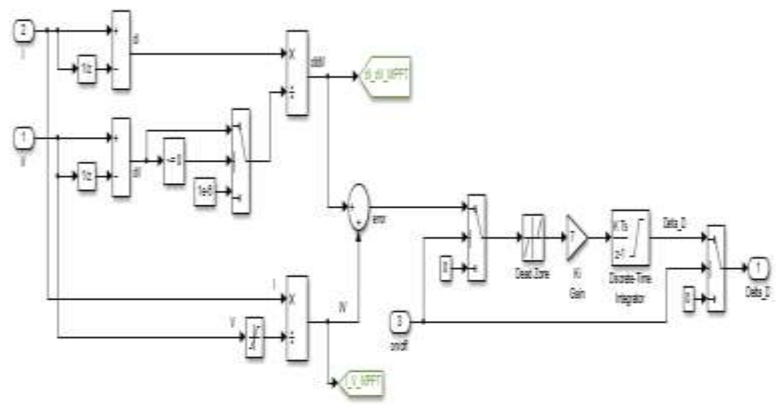

Figure 9 (a) proposed algorithm MPPT [13]

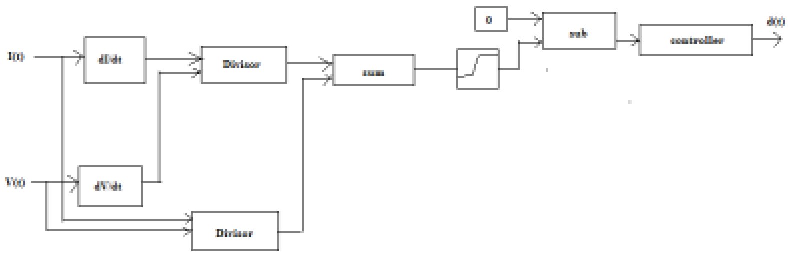

Figure 9 - (b) Proposed MPPT algorithm [13]

A. Grid Synchronise 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].

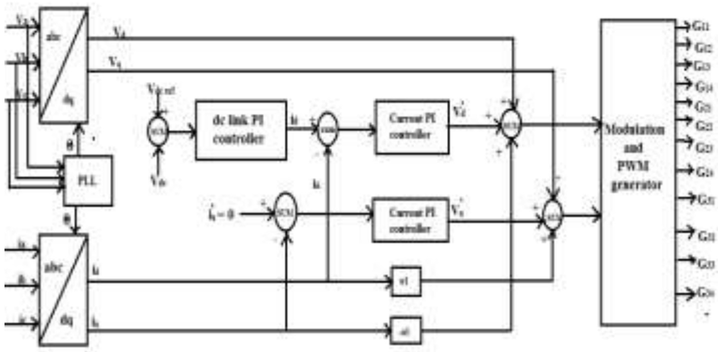

Figure 10 Typical control strategies for VSC control [9]

B. DC Voltage Controller

The DC voltage controller regulates the voltage up to 500 V. In fig. 10 shows the dc voltage regulator in control strategy 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 the 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

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. The simple flow chart for controlling fuel cell input current according to PV generation is shown in fig. 12.

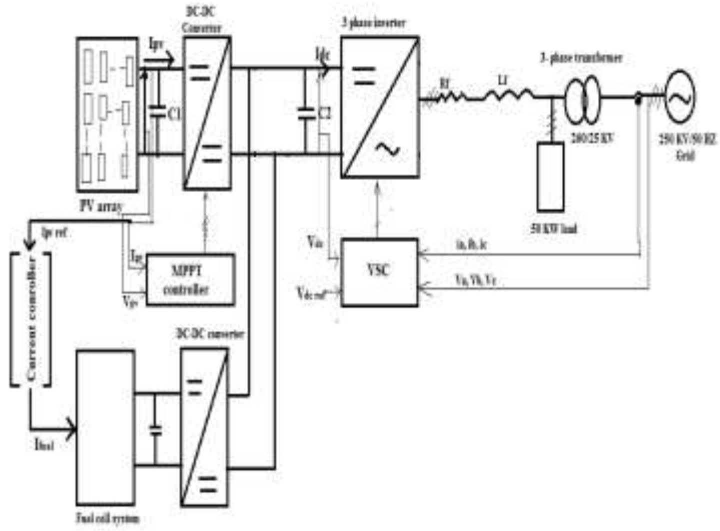

Figure 11 Detail control strategy of PV-FC system [9]

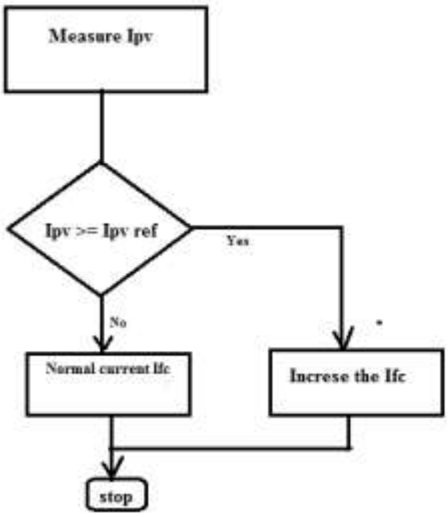

Figure 12 - Flow chart for control the Ifc

VI. Simulation Results And Discussion

In fig. 13 (a), (b) shows the simulation characteristics of 36 W PV modules.

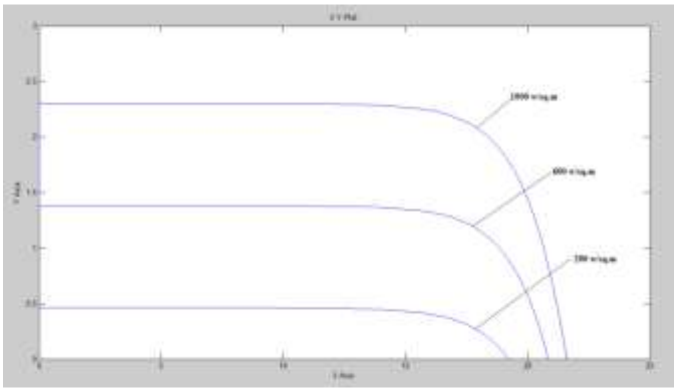

Figure 13 - (a) I-V characteristic of PV module with varying irradiation [11]

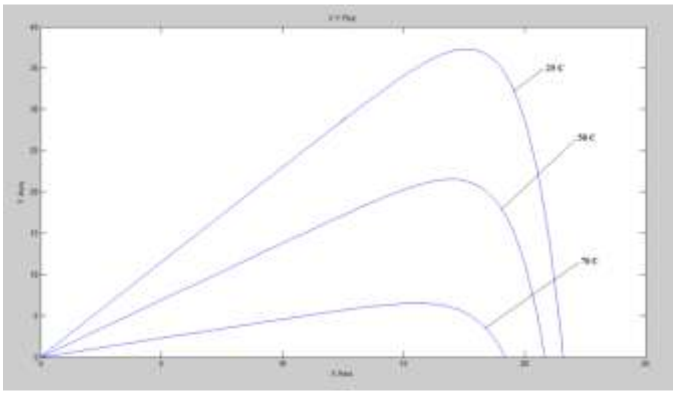

Figure 13 – (b) P-V characteristic of PV module [11]

In fig. 14-(a), (b), and (c) show the I-V, P-I and dynamic response of 500 W PEMFC SR-12 module.

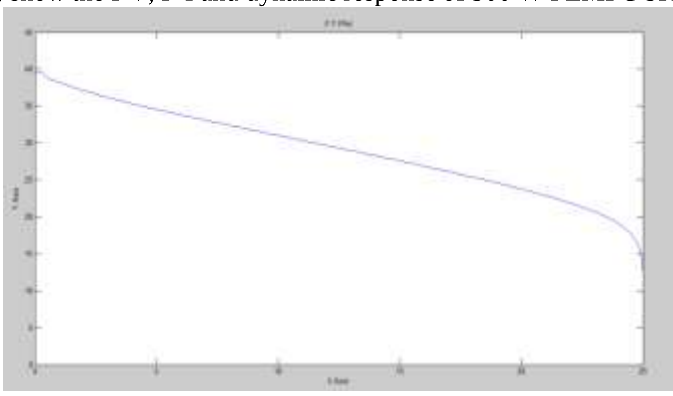

Figure 14 - (a) I-V characteristic of PEMFC SR-12 module [7]

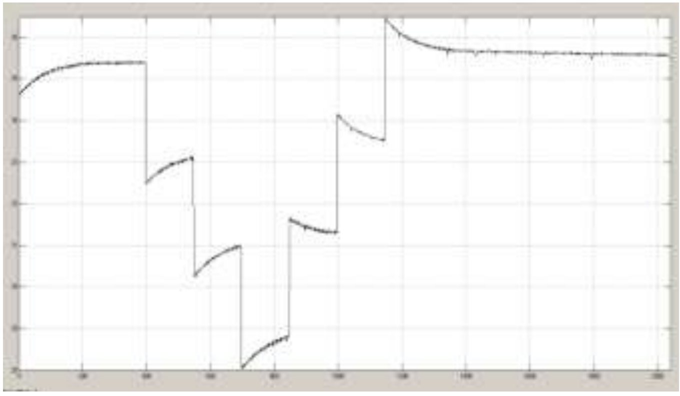

Figure 14 - (b) Voltage under dynamic condition of PEMFC [7]

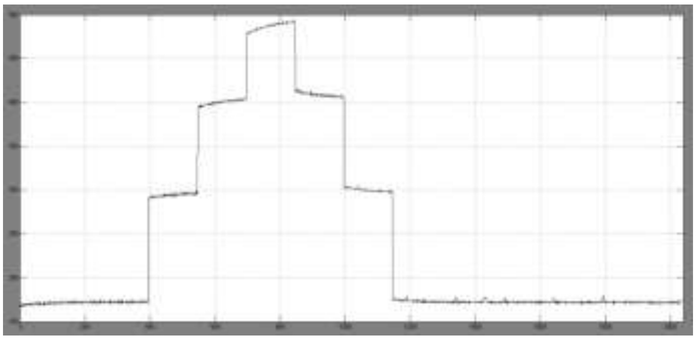

Figure 14 - (c) Power under dynamic condition of PEMFC [7]

A. PV SYSTEM

In fig. 15 present the different results for 100 KW grid connected system with 50 KW load with radiation 1000W/m^2 and operating temperature 25°C. In fig. 15-(a) show the excess grid power approximate 50 KW supply to the grid. Fig. 15-(b) and 15-(c) present the three phase grid voltage and current graph in large view. Also, present the single phase grid voltage and current in fig. 15-(d).

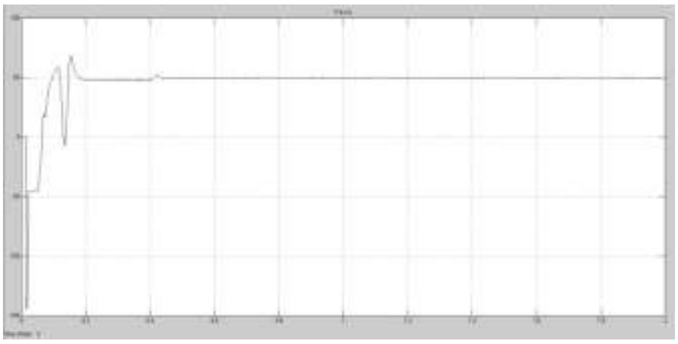

Figure 15 - (a) grid power

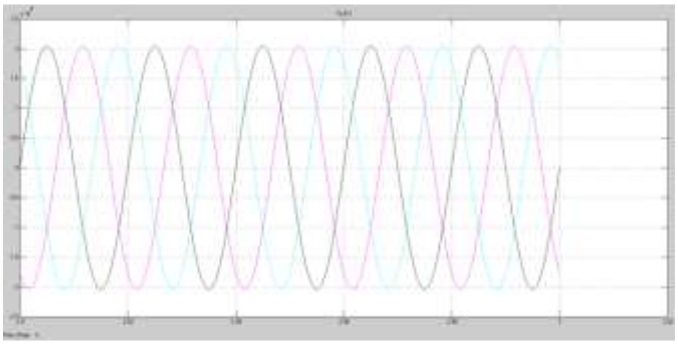

Figure 15- (b) - Three phase grid voltage

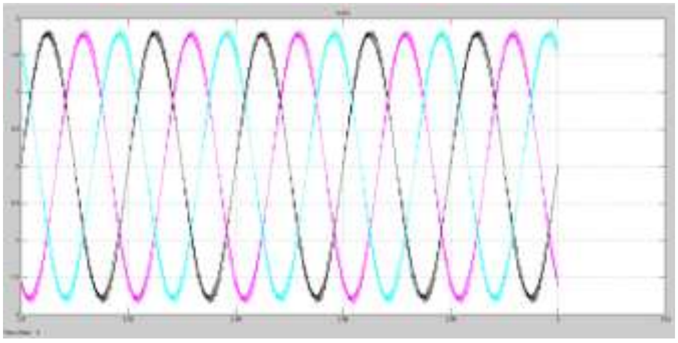

Figure 15 - (c) Three phase grid current

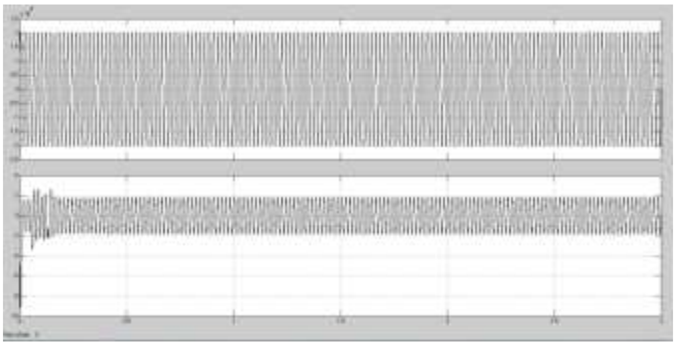

Figure 15 - (d) Vab grid voltage and Iab grid current

Figure 15 - (e) output of boost Vdc and modulation index

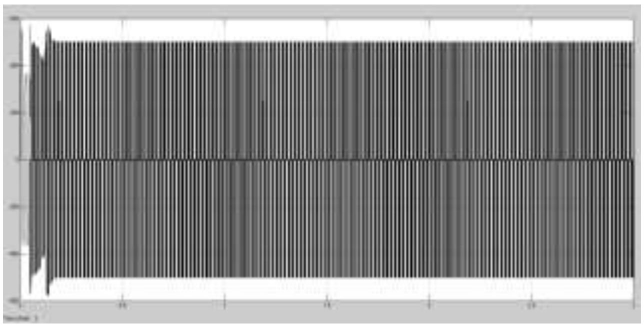

Figure 2 15 - (f) voltage output of the Vab VSC

B. PV – FC Hybrid System

Fig. 16 shows the different results obtain from PV-FC hybrid system. Here, total generation is 116.5 KW. Approximately 66.5 KW excess power feed to the grid and 50 KW power is consume by the load. Fig. 16 – (a) present the approximately 66.5 KW load feed to the grid. Fig. 16 – (b) and (c) shows the three phase grid voltage and current respectively. Fig. 16 – (d) present the single phase grid voltage and current. Fig 16 – (e) shows the single phase voltage (V_{ab}) of voltage source inverter. Fig. 16 – (f) & (g) show the dc output voltage of boost PV side, modulation index and DC output voltage of boost FC side.

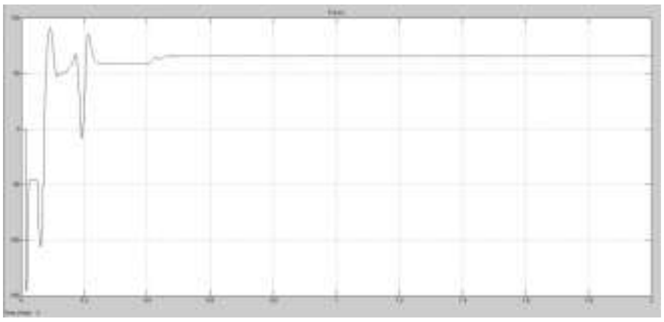

Figure 16 – (a) Grid power

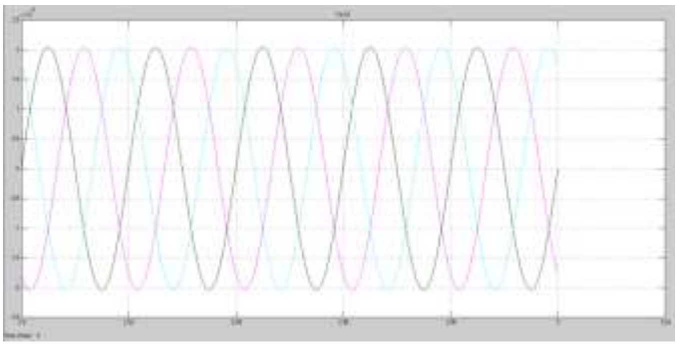

Figure 16 – (b) Grid three phase voltage

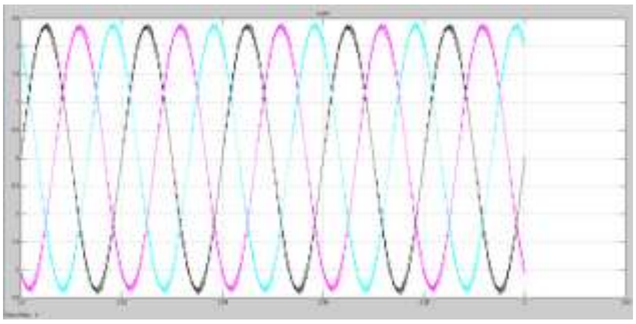

Figure 16 – (c) Grid three phase current

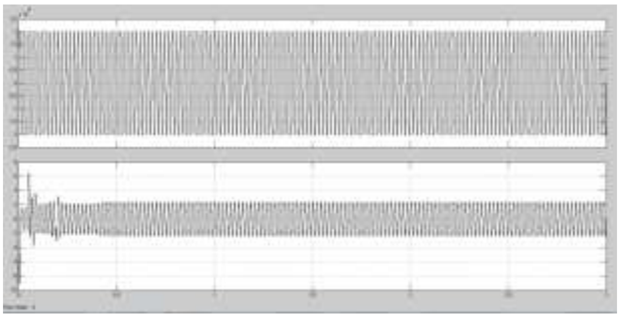

Figure 16 – (d) Single phase grid voltage and current

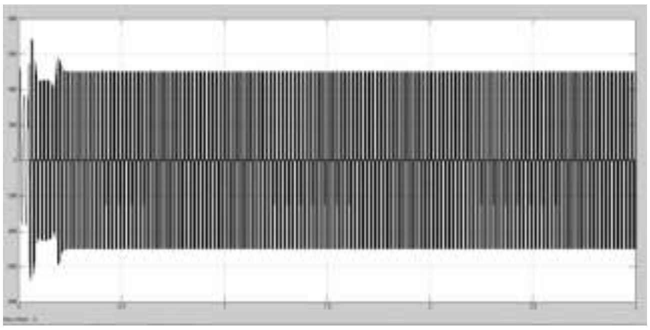

Figure 16 – (e) Vab VSC

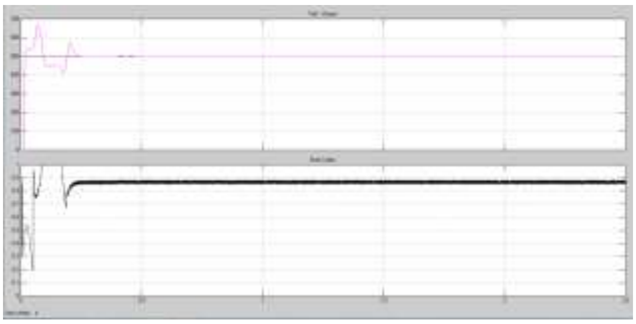

Figure 16 - (f) Vdc output voltage of boost PV and modulation index

Figure 16 – (g) Vdc output voltage of boost Fuel cell

C. PV – FC Hybrid System With Input Current Control of Fuel Cell

In fig. 17 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 fig. 17-(a), present the excess grid power approximate 50 KW supply to the grid. As shown in fig. after the 1.5s grid power is disturbed for few seconds. But, it again takes steady value near up to 50 KW. Fig. 17.-(b) presents the three phase grid voltage and current and also presents the single phase voltage and current in 17-(c). In fig. 17 - (d) show the boost output of PV side with approximate 500 V DC and graph of modulation index. In fig. 17 – (e) present the boost output of fuel cell with approximately 500 V. In fig. 17 – (f) present the single phase (V_{ab}) voltage of VSC. Fig. 17 – (g) shows the sun radiation varying from 850 W/m^2 to 1000 W/m^2.

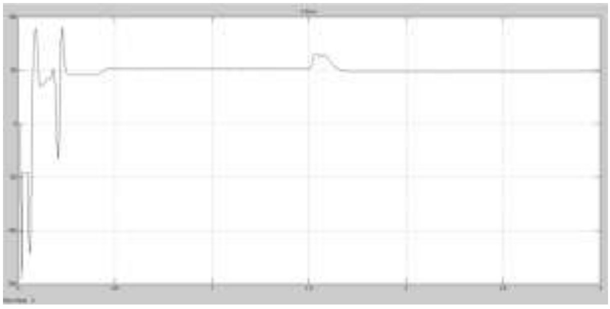

Figure 17- (a) Grid power

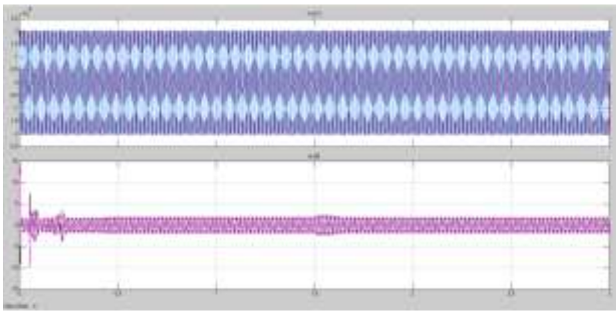

Figure 17- (b) Grid three phase voltage and current

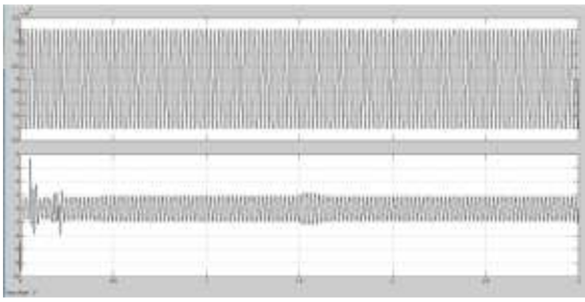

Figure 17-(c) Vab and Iab of grid

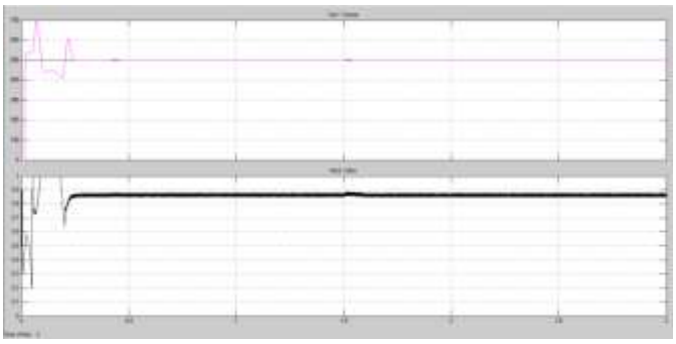

Figure 17-(d) Output Vdc of boost and modulation index

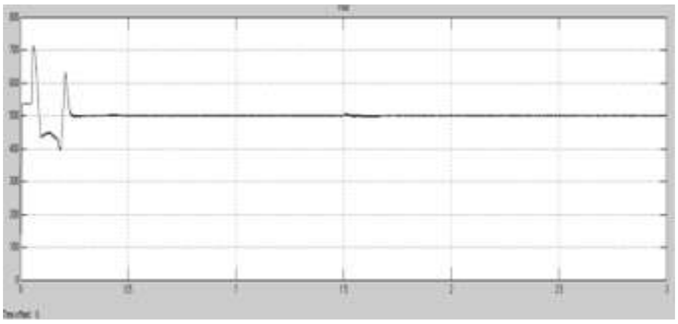

Figure 17-(e) Vdc output of Boost PEMFC

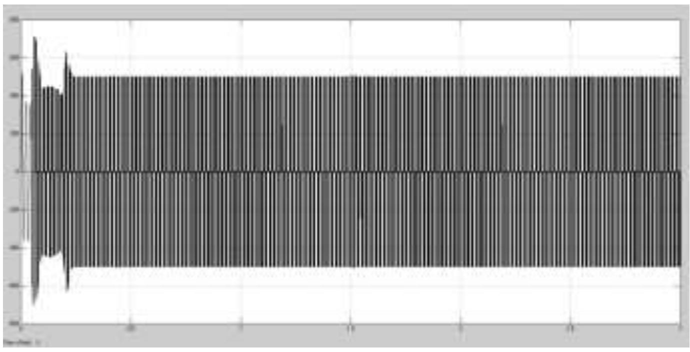

Figure 17-(f) Voltage Vab VSC

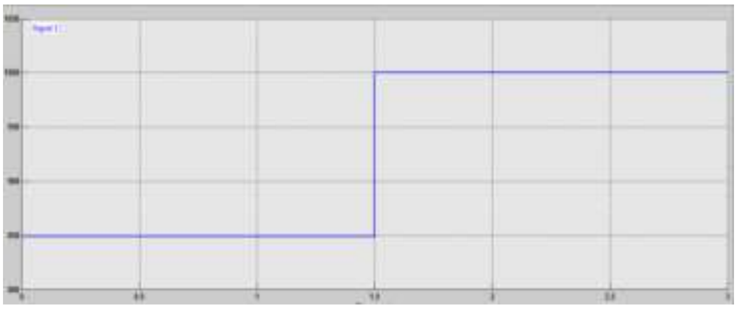

Figure 17 - (g) Sun irradiation

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

Table 1 Data for 36KW PV module [11]

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

Table 2 specification for SR-12 PEMFC 500 W stack [7]

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

Table 3 Electrical parameters for SR-12 PEMFC [7]

(V)	58.9
(V/K)	0.00085
(s)	80.0
	0,00333
	20.145
a (V/K)	-0.1373
(	1.2581
(	0.00112 * (T-298)
(	$-1.6777 * 10^{-6} I^5 + 1.2232 * 10^{-4} I^4 – 3.4 * 10^{-3} I^3 + 0.04545 I^2 – 0.3116I$
(	$5.211 *10^{-8} I^6 – 3.4578 * 10^{-6} I^5 + 8.6437 * 10^{-5} I^4 - 0.010089 I^3 + 0.005554 I^2 – 0.010542 I$
	22000
(	0.0347
	0.1F (4.8 F for all cell)
(	0.2793
(	0.001872 * I
(	-0.0023712 * (T-298)
(	0.080312
(	0.0002747 * (T-298)

DC link reference voltage (V)	500V
Transformer Primary (KV)/ secondary (V)	25KV/ 260
Grid nominal line voltage (KV)/ frequency (HZ)	25/50