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Analysis of Load Power Flow Control with Hybrid PV-Fuel Cell System

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Abstract: Hybrid PV system has many advantages and thus find many applications due to increase in demand of renewable energy. Single renewable energy technology is less reliable and efficient due to intermittent nature of renewable energy source. Purpose of hybrid system is to reduce fluctuation in power supply, increase reliability and enhance the system performance and flexibility. In this paper a small scale hybrid PV-fuel cell system is proposed for supplying constant power to a load. Variation in PV insolation level is simulated, which causes power generation to vary and this gets reflected as variation in DC bus bar voltage. This bus bar voltage is sensed by Fuel cell controller and power is drawn from fuel cell to compensate reduction in available power. This reduces power fluctuation at load. It can be seen that by maintaining constant bus bar voltage, not only power profile but voltage fluctuation across load is also improved. Power flow to load can be controlled by adjusting reference voltage. Efficiency of Fuel cell varies depending upon requirement of power drawn. Fuel cell operates in ohmic region and exhibit excellent operating performance. Overall fuel consumption of fuel cell is minimized as it is used to supply only deficit power as demanded by load when PV is not supplying rated power and thus it finds application in many small-scale critical applications.

I.INTRODUCTION

Nowadays electricity is most needed facility for our day to day life for human being. Conventional energy source and non-conventional source are the two way for generation of electricity. Electricity energy generation by conventional sources includes generation from nuclear, coal etc.

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Convention sources has advantage that it can be used to generate large amount of power which varies very little and thus it can be used as base load plants. As resource of conventional energy is depleted day by day and the main drawback is waste like fly ash, nuclear waste, emission of greenhouse gases etc., there is need to find alternative solution for power generation.

Renewable sources like solar, wind, tidal are clean source of energy and have almost no running cost and are environment friendly. But they have issues like high capital host, need of technological development, cannot be setup in places where sufficient renewable source is not available and intermittent nature of available source. But the drawbacks of non-conventional/renewable are less as comparison to conventional sources and thus they can safely augment existing conventional power system [1].

Most of the energy on Earth in form of light and heat and this is form of solar energy. Solar energy is energy that receive from sun and it has long life span. It is freely available on earth and better distributed than other renewable energy sources. India has focused on developing renewable energy to achieve 175 GW of renewable power by 2022. Solar cell or PV cell is semiconductor device which convert solar energy into electrical energy. Solar energy's main drawback is that it is not available in rainy season, night, bad weather condition [2-3].

Fuel cell are the upcoming technology for the future due to its efficiency, weight, performance, environment friendly and efficient transportation. Fuel cell are the device which can generate electricity in without emission of harmful gases and waste. Fuel cell directly converts chemical energy into electrical energy. There are different types of fuel cell which are used according to requirement of end user [4].

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PV cell and solar cell both are the renewable energy topology which combine together and make the Hybrid renewable system. The main advantage of this hybrid system is that when PV cell is not providing sufficient power to the grid or load then fuel cell will work and provide deficient power. At night or bad weather condition the amount of solar energy is not sufficient to fulfil the requirement of grid at that time fuel cell will supply power [5].

Fuel cell is a power generation device. It is an efficient and cleanest technology. It produces power by combining hydrogen with oxygen. It consists two electrodes [6 7]. PV cell energy depends upon the cell temperature and weather condition [8]. But the fuel cell does not dependent on

weather conditions. Mostly Proton exchange membrane fuel cell(PEMFC) is preferred [9-10]. Final product of Fuel Cell is water and heat only. However, fuel cell has several shortcomings and major challenge for fuel cell is its high cost and lack of durability [11-13]. Application of fuel cell are aircraft, buses, passenger vehicles. High voltage is obtained by connecting in series a number of individual cells. Fuel cell can provide average and permanent power demand [14-17]. The system of fuel cell stack has relatively fewer moving parts (valves and reactant pump) which produce little fraction [18]. The cost of fuel cell vehicle is higher than battery electric vehicles [19]. But efficient energy management can make them competitive with other technologies for EV too [20].

Proposed system is simulated and result is analyzed for different sets of input value. It is seen that Fuel cell supplies power when PV array power gets reduced from rated power. Power flow by fuel cell stack is controlled by adjusting duty cycle of fuel cell boost converter and attempting to making DC bus bar voltage constant. Constant power is obtained at load, though there are some transient during large change of power supplied by PV system due to inertia of reactive elements and operating speed of sensing equipment.

II. PROBLEM DEFINITION

A. Input Information

Input information in case PV system supplying isolated load is taken considering following factors into account: available solar insulation and ambient temperature, variation in loading. With variation in insulation of solar power, there is variation in current of PV array and with variation in ambient temperature, there is variation in output voltage of PV Array.

In this paper only variation in solar insolation is considered. This condition ensures that variation in DC bus bar voltage is produced only due to mismatch between supply and demand. TABLE I highlights variation in output power of PV array for different values of solar insolation.

TABLE I. PV ARRAY POWER PROFILE

Time(in sec)	Solar Insolation (in W/m²)	PV array Output (in Watts)
0.0	1000	2554
0.6	800	2062
1.4	900	2309
2.2	700	1809
3.0	600	1554

The block diagram of proposed system as shown in fig 1, consists of two renewable sources which form a hybrid system and it supplies constant power to the load.

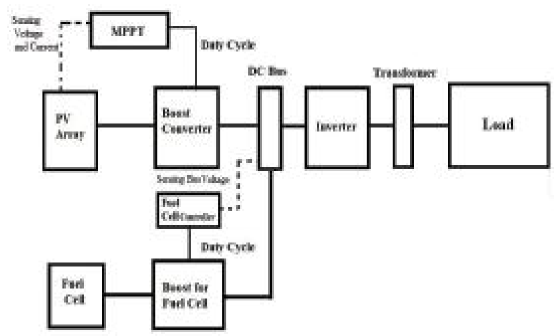

Fig. 1. Block diagram of proposed system

The voltage at bus bar is sensed by Fuel cell controller and power is drawn from fuel cell to compensate the reduction in available power as demanded by the load.

B. Calculation Scheme

By conservation of energy, power supplied to load should be equal to sum of power generated by PV array and Fuel cell. Due to presence of nonlinear elements and loss of

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power in transmission line resistances, switching devices, chokes, losses in converters etc. All power generated isn't totally supplied to load. As almost pure resistive load is considered and losses in power devices is quite less in proposed model, these losses can be neglected for sake of simplicity.

$$V_{load} \cdot I_{load}{}^{*} = \text{function}\,(V_{bus}, I_{bus}) \quad (1)$$

Where V_{load}=load voltage (V)

I_{load}=Load Current(A)

V_{bus}=Bus bar Voltage(V)

I_{bus}=Bus bar Current(I)

Variation in Vbus is produced due to mismatch between supply and demand. Assuming that Vbus is maintained constant by controlling action. And power available at bus bar is given by:

$$P_{bus} = V_{bus} \cdot I_{bus} \quad (2)$$

Where P_{bus} power available at bus bar

Using KVL at bus bar,

$$V_{bus} = V_{pv} = V_{fuel} \quad (3)$$

Where V_{pv}=output voltage of PV boost converter

V_{fuel}=output voltage of Fuel cell boost converter

Using KCL at bus bar,

$$I_{bus} = I_{pv} + I_{fuel} \quad (4)$$

Where I_{pv}=current drawn from PV boost converter

Ifuel=current drawn from Fuel cell boost converter

Variation in solar insolation is reflected as variation in Ipv, assuming that bus bar voltage is held constant. Thus, in order to supply constant power to load, current drawn from fuel cell i.e. Ifuel must be increased. This can be done by controlling fuel cell boost converter.

TABLE II. SYSTEM PARAMETERS

Components	Rating
PV Array	Voltage at maximum power point = 29 V Current at maximum power point= 7.35 A Number of series modules=3 Number of parallel modules=4 Rated Power of Array =2.5 kW
Fuel Cell	Nominal Power= 2.4 kW, Nominal Voltage=48 V Nominal Current= 50 A
Boost Converter(PV Cell)	Inductance= 50 mH, Resistance= 0.1 mΩ Capacitance= 1000 μF
Boost Converter(Fuel Cell)	Inductance= 80 mH, Resistance= 0.5 mΩ Capacitance= 1μF
Transformer	110/230 V, 5 kVA, 50Hz
Load	2.5 kW, 230 V, 50Hz

III. RESEARCH METHOD

In order to see the behavior of the proposed hybrid system, a model has been constructed using a software MATLAB/Simulink. This software is used to solve proposed system and readings is obtained for different sets of input values. Graphs and plots are analyzed and several observations is made. Parameters (as given in Table II) are based

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on other studies[1] and are used in modified form.

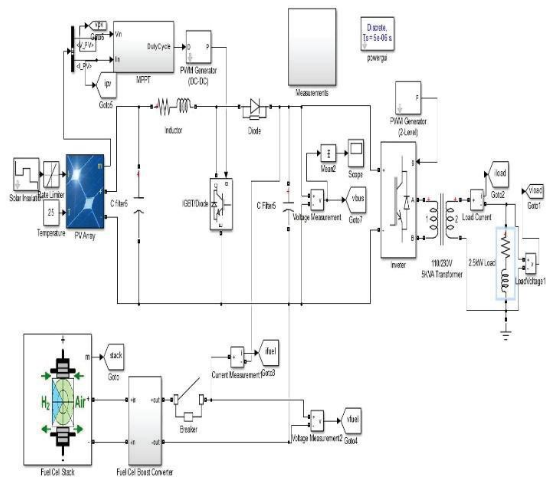

Fig. 2. Simulink Model of proposed system

Diagram of Simulink model is given in Fig 2. It consists of PV array feeding a single phase load. DC boost converter is employed for transferring maximum power to load and inverter is used to converter DC bus voltage into single phase AC voltage.

Fuel cell is connected to DC busbar using boost converter. Boost converter is need at fuel cell system in order to step up low voltage of fuel cell to comparatively higher voltage of dc busbar and also to control power flow from fuel cell to bus bar. In fig 3. Model of Fuel cell controller is given. Here voltage at DC bus bar is sensed and compared to reference dc voltage, in case of mismatched, duty cycle of fuel cell boost converter is changed by step size in order to reduce difference between bus bar voltage and output voltage of fuel cell boost converter. Power delivered to load can be adjusted by changing reference voltage.

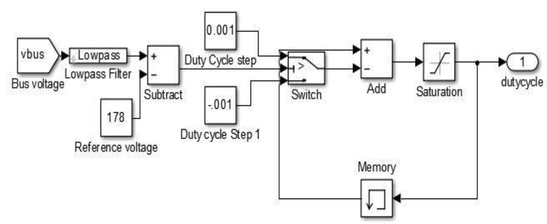

Fig. 3. Simulink Model of Fuel Cell Controller

In this system, a small-scale hybrid PV-fuel cell system is proposed for supplying constant power to a load. Variation in PV insolation level is simulated, which causes power generation to vary and drop in DC bus bar voltage. This bus bar voltage is sensed by Fuel cell controller and power is drawn from fuel cell to compensate reduction in available power.

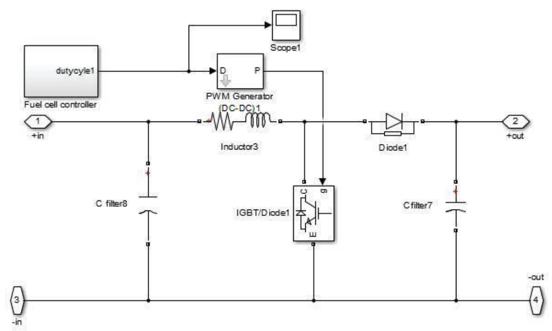

Fig. 4. Fuel Cell Boost Converter

This reduces power fluctuation in load. It can be seen that by maintaining constant bus bar voltage, not only power profile but voltage fluctuation across load is also improved. Efficiency of Fuel cell varies depending upon requirement of power drawn.

IV. SIMULATION RESULTS AND ANALYSIS

Proposed Model is simulated by considering various value of solar insolation as given in TABLE I. Voltage, currents and power at load, fuel cell and PV array is sensed. Duty cycle of fuel cell is adjusted by monitoring bus bar voltage and comparing it to reference value, in order to ensure constant power supplied to load.

TABLE III. Load Power Profile

Time(in sec)	Load Real Power (in Watts)
0.0	2572
0.4	2572
0.6	2479
1.4	2496
2.2	2247
3.0	2426

From TABLE III, it can be seen that load profile is maintained constant even when there is large variation in power delivered by solar PV array. At time 2.2 sec there is undershoot in load power as there is large variation in solar power and system takes some time to settle to final value. Duty cycle of fuel cell is adjusted by monitoring bus bar voltage and comparing it to reference value, in order to ensure constant power supplied to load.

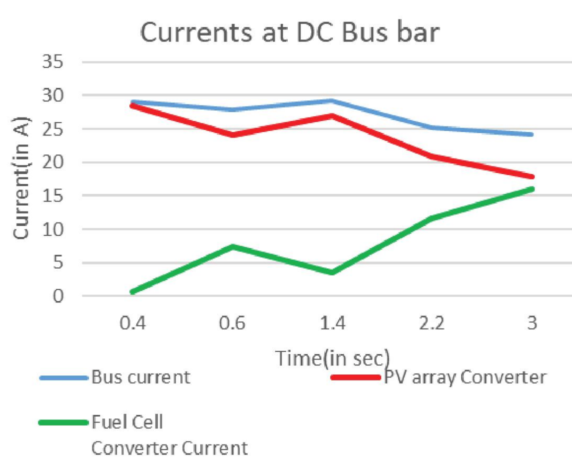

Fig. 5. Currents at DC Bar

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From fig 5. it can be seen that variation in DC bus current is less during slight variation of PV converter current output from time 0 up to 1.4 sec. After 1.4 sec, large variation in PV array current causes busbar current to fall from 29A to 24 A (17%) whereas drop in PV array current is from 27A to 18 A (37%). Thus, large drop in PV array current is not reflected as large drop in bus bar current.

TABLE IV. FUEL CELL VOLTAGE AND CURRENT PROFILE

Time(in sec)	Fuel cell voltage(in V)	Fuel cell current(in A)
0.4	64.5	0.7
0.6	57.9	7.8
1.4	60.2	3.8
2.2	56.0	12.5
3.0	54.8	16.9

Different values of current and voltage of Fuel cell stack is given in TABLE IV and corresponding V-I characteristics is plotted in fig 6.

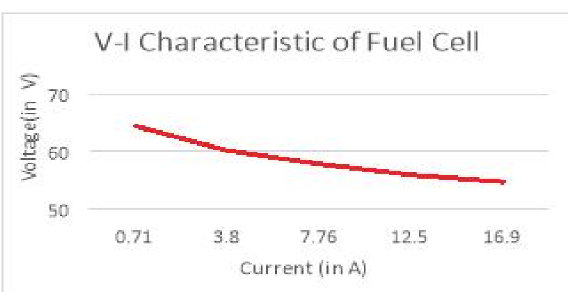

Fig. 6. V-I Characteristics of Fuel Cell

From fig 6. it can be seen with increase in current, output voltage of fuel cell is reduced. It is clear from characteristics that fuel cell is operated in ohmic region as variation in slope is less. This also reduces extra stress on Fuel cell boost converter as when extra power is drawn, excessive reduction in output voltage of Fuel cell stack would lead to excessive voltage boosting requirements.

TABLE V. FUEL CELL AIR AND FUEL CONSUMPTION

Time (in sec)	Consumption (in lpm)	
	Air	Fuel
0.4	1.0	0.07
0.6	10.8	0.76
1.4	5.4	0.38
2.2	17.5	1.22
3.0	23.6	1.65

TABLE V. illustrates rate of consumption varies with increase in power drawn by fuel cell. Depending on maximum deficient power requirements, air and fuel consumption data can be used to design storage requirements.

TABLE VI. FUEL CELL POWER PROFILE

Time(in sec)	Fuel Cell Power (in Watts)
0.0	147
0.4	147
0.6	535
1.4	231
2.2	719
3.0	925

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From the TABLE VI fuel cell power is same during 0.0 to 0.4 sec as during this time PV Array supplies rated power. Solar insulation is decreases from 1000 W/m2 to 800 W/m2 during this interval output of PV cell is decrease from 2554 W to 2062 W. After 0.4 sec output of fuel cell is increased from 147 W to 535 W. At 0.6 sec PV output is decreases so at this time fuel cell fulfil and compensate the requirement of load.

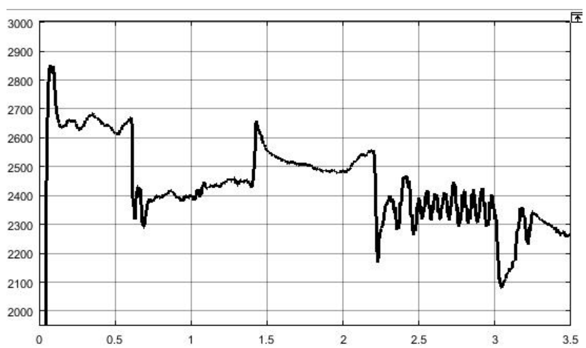

Fig. 7. Load Power Profile

From fig 7. it can be seen that power supplied to remains constant within acceptable limits (<2.5% during steady state and maximum 10% during heavy transient). Voltage variation at load also remains within 5% threshold as seen in fig 8.

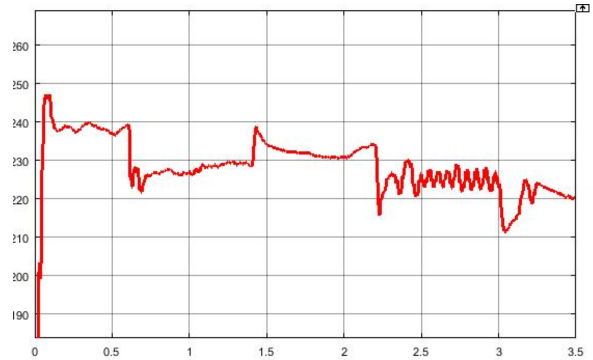

Fig. 8. Load RMS Voltage

V. CONCLUSION

Hybrid PV-fuel cell system has many advantages and applications as it can supply constant power to small scale critical load. Proposed model allows smooth control of power supplied to load. The bus bar voltage sensed by Fuel cell controller and power is drawn from fuel cell to compensate reduction in available power from PV array.

It is seen that even for large reduction in supplied current by PV array, reduction in of current at DC bus bar is less as fuel cell compensate reduction in current. The efficiency of Fuel cell varies depending upon requirement of power drawn. Overall fuel consumption of fuel cell is minimized as it is used to supply only deficit power as

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demanded by load when PV is not supplying rated power. From V-I characteristics of Fuel cell it was also seen that it operates in nearly ohmic region, which reduces excessive stress on converters and also ensures high performance.

In this paper, it can be seen that PV-Fuel cells offer good alternative to other form of energy sources where there is requirement of constant power and voltage profile even when there is variation in load with minimal consumption hydrogen and oxygen in fuel cell. For future scope, there is possibility of using surplus power of PV to electrolyze water (if water is used in production of hydrogen) for production of hydrogen This would make system somewhat self sufficient in large extent.

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