2023 International Conference on Power Electronics and Energy (ICPEE)

Control and Energy Management of DC Nano Grid-Connected Solar PV, Fuel cell and Battery Energy Storage System

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2023 International Conference on Power Electronics and Energy (ICPEE) | 978-1-6654-7058-2/23/$31.00 ©2023 IEEE | DOI: 10.1109/ICPEE54198.2023.10060628

Abstract— **The interconnection of renewable energy sources with the utility grid, such as photovoltaic (PV) and fuel cells (FC), is a solution that is effective in meeting load demand on the distribution side. The rising demand for energy management systems can be attributed to the widespread use of battery energy storage systems (BESS) in the utility grid. An effective energy management system is proposed in this study for use in a PV and FC-based DC nano grid with BESS, and several operating modes are analyzed and addressed. The most important aspect of it is that it keeps the DC voltage consistent throughout the grid. With the help of the MATLAB/Simulink software tool, many simulation case studies are carried out in this research.**

Keywords— Photovoltaic, Fuel cell, Nano grid, Energy Management System

Nomenclature:

ΔG	Gibbs free energy in ($\frac{J}{mol}$),	R_C	contact resistance of the electron current
F	Faraday constant (96487 C)	R_M	resistances of the PEM
ΔS	Change value of entropy	r_m	resistance of electrolyte membrane (Ω.cm)
T	Working temperature of fuel cell	t_m	thickness of electrolyte membrane (cm),
T_O	reference Temperature	A	activation area of fuel cell (cm^2),
P_{H_2}	Hydrogen pressure	V_{ohmic}	ohmic overvoltage drop
P_{O_2}	oxygen pressure	λ_m	Water content of membrane.
R	gas universal constant (8.314$\frac{J}{K.mol}$),	n	number of electrons involve in the reaction
E_{ners}	Reversible voltage output of the single cell open circuit.	i_L	limiting current(A)
fc_i	($i = 1 - 4$) parametric value for fuel cells	NFC	number of cells
CO_2	Carbon dioxide	VFC	Fuel cell output voltage(V)
I_{FC}	fuel cell current (A)	PFC	Fuel cell output power(W)
V_{act}	Activation voltage loss		
ΔG	Gibbs free energy in ($\frac{J}{mol}$),	R_C	contact resistance of the electron current

F	Faraday constant (96487 C)	R_M	resistances of the PEM
ΔS	Change value of entropy	r_m	resistance of electrolyte membrane (Ω.cm)

I. INTRODUCTION

PV and Fuel Cells are the most advanced renewable energy sources, and their advantages such as dependability, eco-friendliness, and low pollutant emissions are driving rapid growth in power generation technologies [1]. Despite their advantages, they had significant drawbacks like cloudy climates, partial shading for PV, and the initial cost and availability of fuel for FC that prevented them from operating in a stand-alone mode[2]. Interconnections of two or more sources along with battery energy storage systems are needed to supply seamless power to the load. In this paper, a DC nanogrid with PV and FC along with a battery has been proposed [3].

Recently, DC Nano Grids have caught the attention of researchers because of their higher quality of power and greater reliability and efficacy of renewable resources [4]. [5] in this PV with the maximum power point Tracking will serve as the primary source, and fuel cells along with batteries will handle peak demand. If the sources are properly managed, the proposed system offers higher energy density. Many authors [6–10] proposed a variety of energy management techniques based on source selection and load availability. [7], the author has proposed a dynamic power management control, when all the sources, storage, and loads are connected directly at the DC link. The power management algorithm needs to consider the microgrid's smooth operation in various modes and state-of-charge limit conditions for the hybrid energy storage system.[11], the author has proposed intelligent proportional integral and derivative controller parameters are tuned using a binary genetic algorithm and a real-coded genetic algorithm by formulating an optimal control problem. However, a standalone fuel cell system finds it difficult to meet short–term peak variations in the load.[12],The researcher proposes optimizing the hydrogen storage operation with an advanced control strategy that excels in various EMS techniques for DC grid-connected PV, FC, and battery for a stand-alone application.[13],In this article, the author proposes a household Nano-grid PV system energy management approach. The long-term charging and discharging of the battery are scheduled optimally using the

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rolling optimization method, which is used to tackle the maxed integer linear Programming problem.

In this paper, the authors focused on developing an Energy Management control strategy for a PV–FC–Battery DC Nano grid that will aid in obtaining maximum power from the sources (PV and FC) and optimally charging the battery. The proposed EMS maximizes solar PV utilization while accounting for the FC system's slow response time, as well as considerations for DC bus voltage regulation, battery SOC, battery power limitation, and load shedding. For typical DC load applications, excess power in the system should be managed within the capacity of the storage units by derating the PV system and charging the battery. In this Modeling of PV, FC battery Based DC Nano grid and simulated several case studies are carried out for EMS by using MATLAB/Simulink software tool.

The rest of the paper is organized as follows: Section 2 discusses the modeling of PV, FC, battery, and control techniques. Section 3 deals with the energy management system (EMS), Section 4 discusses the simulation results, and finally the conclusion is in Section 5.

II. SYSTEM MODELLING

A. Modeling of Solar PV and its characteristic:

PV Module is a combination of solar PV cells; Solar PV Cell can be modeled [14], [15] and represented as a single diode Model based on the Mathematical outline is given below.

$$I_{pv} = I_{ph} - I_O - \frac{(V_{pv}+I_{pv}R_S)}{R_{sh}} \quad (1)$$

$$I_{ph} = \{I_{SC-STC} + K_i(T - T_r\} \frac{G}{G_{STC}} \quad (2)$$

$$I_o = I_{o1}\left(exp\left(\frac{q(V_{pv} + I_{pv}R_s)}{Ak_bT}\right) - 1\right) \quad (3)$$

Where I_{pv}, V_{pv} is the output current, voltage of the PV cell,I_{ph} is the generated photocurrent, K is the Boltzmann's constant i.e. $1.38xe^{-23}$, R_{sh} , R_s are shunt and series resistance, q is the electron charge $1.602x10^{-19}$ C, $I_O$is flow through diodes depends on PV cell reverse saturation current . $G_{STC}$is the standard solar irradiation quantity on a solar PV cell i.e.(1000 W/m2),T is ambient temperature, A is diode ideality factor, T_r is the reference temperature, $I_{SC_{STC}}$ is the short circuit current at STC, $V_t$is the thermal voltage of the diode,I_{01} isTemperature dependent current component , G is solar irradiation (W/m^2). Parameters of the PV cell is given in table.1

The output voltage of a Boost converter is determined by the duty cycle for balanced operation using the MPPT procedure. The interconnection for that input and output voltage is a result of the duty cycle.

$$\frac{V_O}{V_{in}} = \frac{1}{1-D} \quad (4)$$

WhereV_O=Output Voltage, V_{in}=Input Voltage and D=Duty cycle.

Single diode model representation along with characteristics has shown in Fig.1

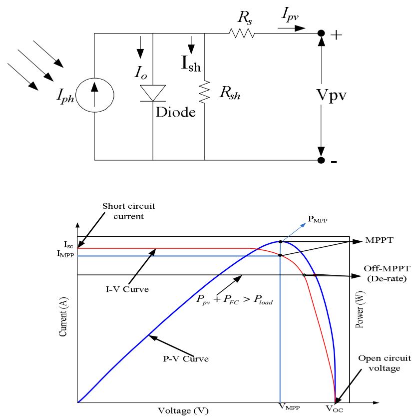

Fig.1 single diode model for solar PV and its characteristics

Table 1. Specifications for PV array at STC (1000 W/m2 irradiance, 25°C device temperature).

power	59.85W
MPP's voltage	17.1 V
MPP's Current	3.5 A
Voltage at the open circuit	21.1 V
current at the Short-circuit	3.8 A
In a module, the number of solar cells in sequence	36
Each string has a certain number of modules.	4
Number of modules connected in parallel	2
Temperature coefficient of a short-circuit current cell	0.007%
Temperature of the nominal working cell	40^0

B. Modeling of Fuel Cell:

The output voltage of the fuel cell [16], [17] depends on the internal voltage drops i.e. it is the difference between reversible voltage (E_{nernst}) to the internal voltage drops ($V_{act}, V_{ohmic}, V_{con}$). Internal drops are caused because of the existence of voltage loss caused by activation, concentration, along with resistive losses. The output voltage of the fuel cell V_{cell} *is* given in Equation (5), and The mathematical Model of fuel is represented in Fig.2 parameters of the fuel cell is given in table.2.

$$V_{cell} = E_{Nernst} - V_{act} - V_{ohmic} - V_{con} \quad (5)$$

Where reversible voltage E_{nernst} represented as:

$$E_{nernst} = \frac{\Delta G}{2F} + \frac{\Delta S}{2F}(T - T_o) + \frac{RT}{2F}\left[ln(P_{H_2}) + \frac{1}{2}ln(P_{O_2})\right] \quad (6)$$

Activation voltage loss V_{act} is given in the Tafel equations as:

$$V_{act} = [\xi_1 + \xi_2 T + \xi_3 T ln(C_{O_2}) + \xi_4 T ln(I_{FC})] \quad (7)$$

$$V_{ohmic} = I_{FC}(R_M + R_C) \quad (8)$$

$$V_{Con} = -\frac{RT}{nF} * ln\left(1 - \frac{I_{FC}}{i_L A}\right) \quad (9)$$

The variables and constants of the above equations are represented as

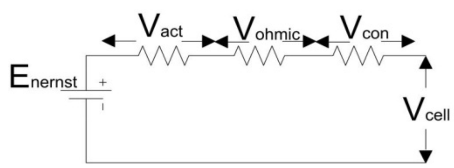

Fig.2 Modeling of Fuel cell

Table.2 Specifications for fuel cell modules

Rated capacity	234W
Cells count (nfc)	48
Temperature of the working environment	$5-35^{0}C$
Pressures in use	PH2 :0 to 5 atm
The stack's maximum heat power	500 J/(kg K)

C. Modeling of Battery:

The presence of nonlinear nature, the battery's effective representation in controllers, has evolved into another issue. There are several battery behavior simulation models already in existence, each with differing degrees of simulation behavior complexity. The most fundamental and often used battery type is an ideal voltage source connected in series with either a fixed internal resistance. Another common battery type is the Thevenin, which also has the ideal no-load battery voltage, series internal resistance, and a parallel connection of overvoltage resistance and capacitance. More suitable methods have been recommended to take into consideration the nonlinear factors. Figure.3 could be represented using the equations below, and the parameters of the battery is given in table.3.

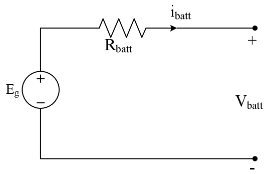

Fig.3 Equivalent circuit of the Battery

$$V_{batt} = E_g - i_{batt}R_{batt} \quad (10)$$

$$E_g = E_{go} - K\frac{Q}{Q-\int i_{batt}\,dt} + Ae^{(B.\int i_{batt}dt)} \quad (11)$$

Table.3 Battery Specifications:

Choice	**Lead acid**
Rating in Ampere hour	2 Ah
Nominal voltage	24 V
Charging rate	C/10

D. Control Strategy for Constant DC Voltage

Bidirectional DC/DC converters are used in BESS to control the common DC link voltage. Any power imbalance between the sources and the demand for the load is taken care of by BESS, which regulates the DC link voltage. Fig. 4 depicts the traditional cascaded voltage and current controller design used for BESS. A reference voltage signal and a PI-based voltage controller are used to compare the measured DC link voltage with each other. The output of the controller is considered battery reference current and given equations (12) and (13).

$$\Delta v(t) = V_{dcref(t)} - V_{dc(t)} \quad (12)$$

$$i^{*}_{bat}(t) = k_p\Delta v(t) + \int \Delta v(t)\,dt - i_{pv}(t) - i_{fc}(t) \quad (13)$$

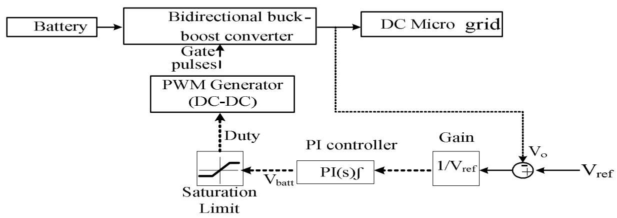

Fig.4 Control of DC link voltage by using PI controller

III. ENERGY MANAGEMENT SYSTEM

Modeling of PV, FC, and battery are discussed in the previous section. In this paper, the use of an energy management technique is required to efficiently organize various RES and ESS that could be distributed across the DC grid and enhances a dispensed energy management technique based on the EMS approach for maintaining power balance and reliable operation of a DC Nano grid under generation and possibly load conditions. The DC Nano grid with BESS has considered in this paper. The PV source is operating with MPPT, and FC is operating in Constant supply Mode connected through DC/DC converter and interfacing with DC grid and utility grid. The battery systems are connected with the common DC grid through a bidirectional DC/DC converter has shown in Fig.5. The battery system discharge or charges under the average excess/deficit power rushes. This proposed EMS method mainly consists of a DC-grid voltage controller with a wide range of load changes, PV, FC and battery ESS as shown in Fig.4, and the EMS operating modes sub cases are described based on flow chart, in Fig. 6.

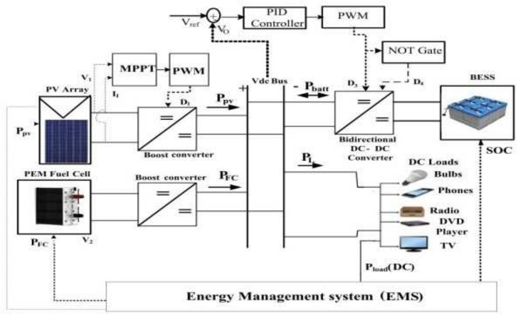

Fig.5 Proposed System for energy Management

There are three different operating modes possible in the proposed system, namely, 1) Excess power mode (EPM), 2) Deficit power mode (DPM), and 3) Floating power mode (FPM). Floating Power Mode is merged with Deficit Power Mode as the BESS can be charged from the DC grid in both modes. Hence, there are two effective operating modes, as shown in Fig. 6

1) Excess Power Mode (EPM):($P_{pv}+P_{FC}>P_{load}$)(Cases:1-5): In EPM, the Average power generated by PV (P_{pv}) and FC (P_{FC}) is greater than the average power required by load (P_{load}). There are two more sub-cases explained under this mode as follows.

Mode A: SoC_{min} and $P_{load\ min}$ divided as Case: 1-2

In this mode, the battery's SoC is at its lowest level and the light load mode is activated. Under this approach, cases 1 to 2 are subdivided. Case.1 RES are operated with P_{pv}=1 and P_{FC}=1 to satisfy the load requirement and charge the battery with excess power. In case.2 P_{FC} is not equal to P_{FCmax}, PV operates at P_{pv}=1 and P_{FC} increases with a modest increment to fulfill the load requirement and charge the battery, as depicted in fig.5's flowchart.

Mode B: SoC_{max} and $P_{load\ min}$ divided as Case: 3-5

In this state, the battery's SoC is at its highest level and the light load mode is activated. As a case, this mode is subdivided into three modes. 3 to 5, in case 3, PV runs in derating mode, i.e., P_{pv}=2, while the fuel cell is operating at

P_{FC}=0. In this state, only PV meets the load requirement, the battery SoC remains in floating mode, and the fuel cell functions in minimum power mode. In case.4 SoC is between the maximum and minimum levels, the load is light; therefore, P_{FC} is maintained at its prior value and PV operates at P_{pv}=1 to charge the battery. Case.5 is identical to case.3 with the exception of the P_{FCmax}. Under these conditions, PV is set to P_{pv}=2 and P_{FC} is set to P_{FCmin}; the battery operates in floating mode according to the EMS technique depicted in Figure 6, and given in table.4.

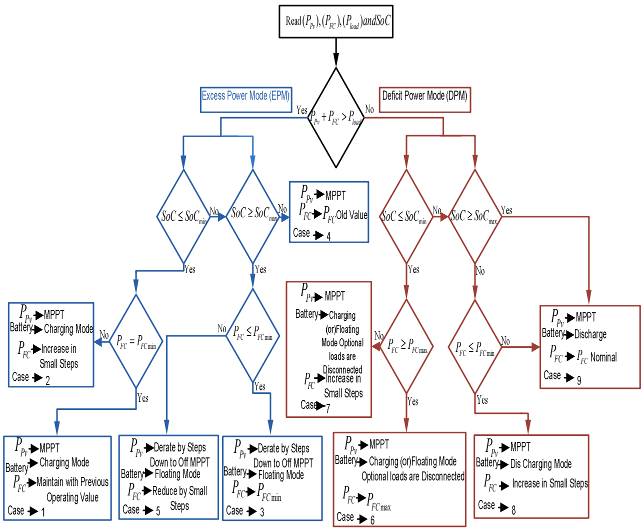

Fig.6 Flowchart for operation of Energy Management System

2) Deficit Power Mode (DPM) :($Ppv+P_{FC}<P_{load}$) (Cases: 6-9):

In DPM, the sum of average power Ppv and P_{FC} is less than P_{load}, This mode further operated in two more sub-cases explained as follows.

Mode C: SoC_{min} and $P_{load\ max}$ divided as Case: 6-7

In this mode, the sub-division is determined by SoC and load demand. In this mode, cases are separated based on the SoC and peak load is enabled. PV and FC operate as P_{pv}=1 and P_{FC}=1 to meet the required load in case.6. While extra electricity generated by RES is used to charge or float the battery if load demand equals source output. Here is a more possible example dependent on SoC_{min}. Scenario 7 is identical to Case 6 except for $P_{FC}=P_{FCmin}$; in this case, P_{FC} increases in modest increments to meet peak load demand and charge the battery; if peak load demand is not met by PV and FC, disconnect the optional loads according to the flowchart in Figure 6

Mode D: $SoC_{max}$and$P_{load\ max}$ divided as Cases: 8–9

In this mode, cases are divided based on the maximum level of the battery's state-of-charge (SoC), and peak load is enabled. Case 8 operates with P_{pv} = 1, at the initial condition P_{FC} = 0 while the battery is in discharging mode, and then gradually increases in small increments until the load demand equals the generation, as shown in Fig. 6. Here is one more conceivable example based on SoC_{max}, i.e. case.9, in which the P_{FC} is under a nominal condition so, P_{pv}=1, the battery SoC is in discharging mode to match the load demand as depicted in Fig. 6.

Table.4 States of PV, FC and Battery under various Modes and cases

MODE	SUB-MODE	CASE	PV State	FC state	BESS State
EPM	MODEA	Case 1	MPPT	FC_{min}	charging
		Case 2	MPPT	FC_{min}	charging
	MODEB	Case 3	De rate	FC_{min}	floating
		Case 4	MPPT	FC_{min}	floating
		Case 5	De rate	Decreasing in small steps	floating
DPM	MODEC	Case 6	MPPT	FC_{min}	Charging or floating
		Case 7	MPPT	Increasing in small steps	Charging or floating
	MODED	Case 8	MPPT	Increasing in small steps	Discharging
		Case 9	MPPT	FC_{min}	Discharging

IV. RESULTS AND DISCUSSION

The effectiveness of the system represented in Figure 4 has been validated by modeling and simulating it in Simulink. SoCmin and SoCmax, as well as load variations, are used to determine the operational mode (constant or dynamic). The operating range for battery SoC is 20% (lower limit) to 80 % (upper limit) to avoid full charge state and dead state conditions. The approaches are enumerated in table.1 after analyzing the critical cases given in the table. The effectiveness of the proposed system is demonstrated through simulated results.

Table.5 Critical Cases

Critical cases	Proposed Cases
$P_{load}>P_{pv}+P_{FC}$ and $SoC \le SoC_{max}$	Case 8&9
$P_{load}< P_{pv}+P_{FC}$ and $SoC \le SoC_{max}$	Case 3&5
$P_{load}< P_{pv}+P_{FC}$ and $SoC \le SoC_{min}$	Case 1,2,4
$P_{load}>P_{pv}+P_{FC}$ and $SoC \le SoC_{min}$	Case 6&7

Case.1: Battery SoC level at 80 %, and load power is greater than PV and Fuel cell power ($P_{load}>P_{pv}+P_{FC}$).

In this case, the total performance of PV and FC will be less than the connected load. Under this condition, RES is operating as PV is producing maximum electricity with MPPT, the battery is in discharging mode, and it's a SoCmax level, and FC is running at a low power rate, in this condition grid voltage is maintained constant as 100V seen in fig.7(f), load power demand is 740 W shown in fig.7(a), to meet the load power demand, RES that is PV supplied the maximum power is 480 W shown in fig.7(c), remaining Fig.7(d), then increase the FC power to meet the load requirement depicted in Fig.7(e), at which point the load power and generating power are equal. To meet the load power requirements and maintain a steady grid voltage, a combination of PV, BESS, and FC is employed to supply the load demand.

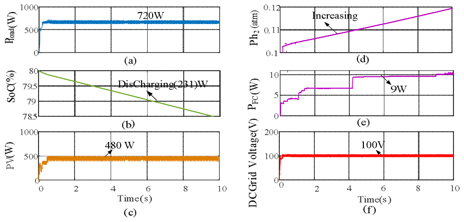

Fig.7 Maximum SoC level, PV and FC power is less than load power (a) Load power (b) Battery SoC (c) PV power (d) Hydrogen pressure (e) FC power (f) DC grid voltage.

Case.2: Battery SoC level is 80 %, load power is less than PV and Fuel cell power $P_{load}<P_{pv}+P_{FC}$).

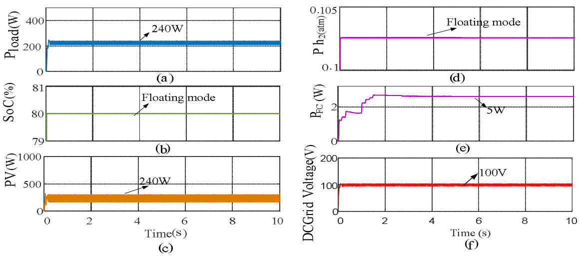

Fig.8 Maximum SoC level, PV and FC power is greater than load power (a) Load power (b) Battery SoC (c) PV power (d) Hydrogen pressure (e) FC power (f) DC grid voltage.

In this instance, the combined PV and FC output power exceed the demand power, and the SoC level is at its maximum. Under this condition, RES are operated as PV is derated with a downgrade to OFF MPPT, battery SoC and FC power are maintained constant with their limits since PV power is nearly equal to load power output, and to prevent overcharging, the power supplied to the Battery is minimized or constant, since there is no storage element or dump loading in the system, and PV generation follows the load demand. DC grid control maintains steady DC grid voltage in this case. Here, the load power is 240W as shown in Fig.8(a), the power generation by PV with a derating power is 240 W as shown in Fig.8(c), and the battery SoC and FC are maintaining their limits with constants as indicated in Fig.8(b) and 8(e), and the DC grid voltage is constant as shown in Fig.8(d) (f).

Case.3: Battery SoC level is 20 %, load power is less than PV and Fuel cell power ($P_{load}<P_{pv}+P_{FC}$).

Load power is minimal relative to PV and FC power, hence battery SoC is low. PV and FC systems are working in MPPT mode to charge the battery and supply DC power to the load. Batteries regulate load power by consuming or distributing electricity based on supply and load demand. In this EMS, PV generation follows power demands; FC generation depends on battery SoC level, when SoC decreases FC hydrogen gas pressure increases, and FC power increases, Vice-versa. As long as SoC and P_{bat} are within limitations, the battery will regulate power as an energy storage device. Maintain steady DC grid voltage. Here load power is 240W shown in Fig.9 (a), power generation by using PV with an MPPT is 480W shown in Fig.9(c), and power generation by using FC with an MPPT is 240W shown in Fig.9 (e). Under this condition battery SoC minimum level so the battery is charging mode shown in Fig.9 (b). DC grid voltage is constant shown in Fig.9 (f).

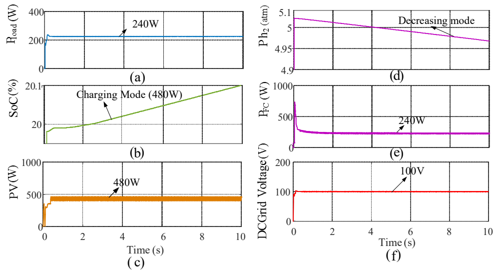

Fig.9 Minimum SoC level, PV and FC power is greater than load power (a) Load power (b) Battery SoC (c) PV power (d) Hydrogen pressure (e) FC power (f) DC grid voltage.

Case.4: Battery SoC level is 20 %, load power is greater than PV and Fuel cell power ($P_{load}>P_{pv}+P_{FC}$).

In this case, PV and FC output power would be lower than the load requirement and battery SoC level. Both the PV and FC are running in MPPT mode, but cannot match the load demand. Since this battery is in the lowest range, deep discharging it to meet load requirements is dangerous. When the battery can't provide, redirect or reduce load demand to PV and FC, which will charge the battery and maintain DC grid voltage. Here initially load power is 740W up to 2s shown in Fig.10 (a), power generation by using PV with an MPPT is 480 W shown in Fig.10(c), power generation by using FC with an MPPT is 240 W shown in Fig.10 (e), in this condition supplied the load demand is equal to generation by using the battery power that is 20W to maintain the load demand. Latter load demand is lowered to 320W for this demand supplied by PV, and FC and charge the battery as indicated in Fig.10 (b), and Fig.10(c), as well as DC grid voltage is maintained (f).

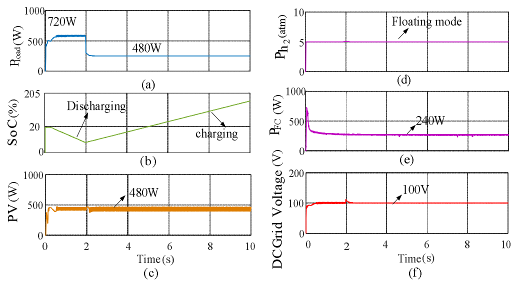

Fig.10 Minimum SoC level, PV and FC power is less than load power (a) Load power (b) Battery SoC (c) PV power (d) Hydrogen pressure (e) FC power (f) DC grid voltage.

V. Dynamics of load variations:

It is responsible for determining whether the EMS is operational whenever there is a quick transition from one load power to another load power in the PV system, FC system, and battery. As with the EMS, load variations are examined as depicted in Fig.11, 12. This graphic depicts the waveforms acquired when measuring the variance of extended load cycles. The simulation experiments were conducted by connecting a resistive-loaded DC connection. In order to simulate the simulation environment, the load will be varied: low load, heavy load. The information includes the DC bus voltage, FC hydrogen pressure, load power, FC power, PV power, and battery state of charge. Initial state minor load power is 140W up to t=2.5sec and the SoC storage device is 80 percent charged. Under these conditions, the PV system is Derated to meet the load requirement (140W), leaving the battery in floating mode and the FC in minimum power mode to keep the DC grid voltage at 100V. Then suddenly increase the load power to 720W from t=2.5sec to 7.5sec, with battery SoC at 80 percent. Under these conditions, the battery must discharge with a power rating of 240W, while the PV system generates the maximum power of 480W, to maintain the load demand, and the FC is in minimum generation mode, to maintain the DC bus voltage at 100V. Long length of load variation with low battery SoC to maintain constant DC grid voltage is depicted in Figure 12.

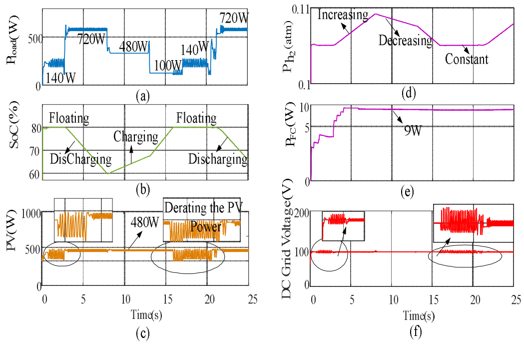

Fig.11 sudden change in load with maximum SoC level (a) Load power (b) Battery SoC (c) PV power (d) Hydrogen pressure (e) FC power (f) DC grid voltage.

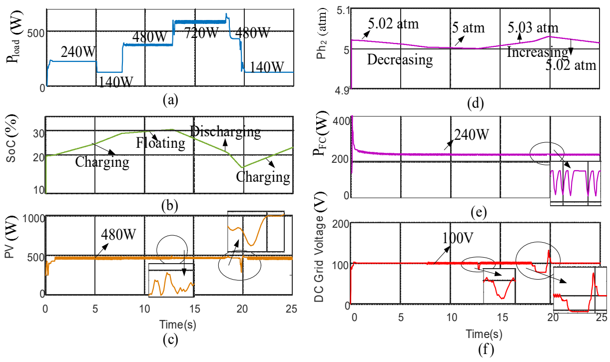

Fig.12 sudden change in load with minimum SoC level (a) Load power (b) Battery SoC (c) PV power (d) Hydrogen pressure (e) FC power (f) DC grid voltage.

V1.CONCLUSION

PV and fuel cells are the most advanced renewable energy sources with advantages like dependability, environmental friendliness, and low pollutant emissions, which are accelerating the development of power-generating technologies. This paper proposes a DC nano grid with PV and FC in addition to batteries. Researchers have presented a control for dynamic power management where all sources, storage, and loads are directly connected to the dc connection. Various EMS strategies for DC grid-connected PV, FC, and battery for stand-alone applications are demonstrated in this work.

REFERENCES

[1] P. Thounthong, A. Luksanasakul, P. Koseeyaporn, and B. Davat, "Intelligent model-based control of a standalone photovoltaic/fuel cell power plant with supercapacitor energy storage," *IEEE Trans Sustain Energy*, vol. 4, no. 1, pp. 240–249, 2013, doi: 10.1109/TSTE.2012.2214794.

[2] T. Selmi, M. Bouzguenda, A. Gastli, A. Masmoudi, and T. Salmi, "MATLAB/Simulink Based Modelling of Solar Photovoltaic Cell Qatar Greener Schools Initiative View project waste to energy and water desalination View project INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH TarakSalmi et al MATLAB/Simulink Based Modelling of Solar Photovoltaic Cell," 2012. [Online].

[3] M. Patterson, N. F. Macia, and A. M. Kannan, "Hybrid micro grid model based on solar photovoltaic battery fuel cell system for intermittent load applications," *IEEE Transactions on Energy Conversion*, vol. 30, no. 1, pp. 359–366, 2015, doi: 10.1109/TEC.2014.2352554.

[4] Sigi C. Joseph, Dhanesh, Chandrasekar V, "Battery Management System for DC NanogridI"nstitute of Electrical and Electronics Engineers, *2018 20th National Power Systems Conference (NPSC).*

[5] M. AzharuddinShamshuddin, T. S. Babu, T. Dragicevic, M. Miyatake, and N. Rajasekar, "Priority-based Energy Management Technique for Integration of Solar PV, Battery, and Fuel Cell Systems in an Autonomous DC Microgrid," *Electric Power Components and Systems*, vol. 45, no. 17, pp. 1881–1891, Oct. 2017, doi: 10.1080/15325008.2017.1378949.

[6] N. Karami, N. Moubayed, and R. Outbib, "Energy management for a PEMFC-PV hybrid system," *Energy Convers Manag*, vol. 82, pp. 154–168, 2014, doi: 10.1016/j.enconman.2014.02.070.

[7] R. K. Sharma and S. Mishra, "Dynamic Power Management and Control of a PV PEM Fuel-Cell-Based Standalone ac/dc Microgrid Using Hybrid Energy Storage," in *IEEE Transactions on Industry Applications*, Jan. 2018, vol. 54, no. 1, pp. 526–538. doi: 10.1109/TIA.2017.2756032.

[8] K. A. Reddy, K. Srinivas, and G. S. Ayyappan, "Simulation of power management circuit in a standalone solar photovoltaic-fuel cell-battery hybrid power system," in *Proceedings - 2015 IEEE IAS Joint Industrial and Commercial Power Systems / Petroleum and Chemical Industry Conference, ICPSPCIC 2015*, Jul. 2017, pp. 168–173. doi: 10.1109/CICPS.2015.7974070.

[9] S. Sikkabut*et al.*, "Control of high-energy high-power densities storage devices by Li-ion battery and supercapacitor for fuel cell/photovoltaic hybrid power plant for autonomous system applications," *IEEE Trans IndAppl*, vol. 52, no. 5, pp. 4395–4407, Sep. 2016, doi: 10.1109/TIA.2016.2581138.

[10] S. Ferahtia, A. Djerioui, S. Zeghlache, and A. Houari, "A hybrid power system based on fuel cell, photovoltaic source and supercapacitor," *SN ApplSci*, vol. 2, no. 5, May 2020, doi: 10.1007/s42452-020-2709-0.

[11] S. Kumar, V. Krishnasamy, S. Neeli, and R. Kaur, "Artificial intelligence power controller of fuel cell based DC nanogrid," *Renewable Energy Focus*, vol. 34, pp. 120–128, Sep. 2020, doi: 10.1016/j.ref.2020.05.004.

[12] M. S. Behzadi and M. Niasati, "Comparative performance analysis of a hybrid PV/FC/battery stand-alone system using different power management strategies and sizing approaches," *Int J Hydrogen Energy*, vol. 40, no. 1, pp. 538–548, Jan. 2015, doi: 10.1016/j.ijhydene.2014.10.097.

[13] Yiyuan Ding, Zhijun Wang, Shichao Liu, Xiaoyu Wang, "Energy Management Strategy of PV Grid-Connected Household Nano-Grid System" IEEE Power & Energy Society. General Meeting (2019 : Atlanta and Institute of Electrical and Electronics Engineers, *2019 IEEE Power & Energy Society General Meeting (PESGM).*

[14] Md. Aminul Islam, Graduate Student Member, IEEE, Adel Merabet, Member, IEEE, RachidBeguenane and Hussein Ibrahim, "Modeling Solar Photovoltaic Cell and Simulated Performance Analysis of a 250W PV Module " *Electrical Power & Energy Conference (EPEC), 2013 IEEE.* [publisher not identified], 2013.

[15] M. Pichan and H. Rastegar, "A New Hybrid Controller for Standalone Photovoltaic Power System with Unbalanced Loads," *International Journal of Photoenergy*, vol. 2020, 2020, doi: 10.1155/2020/5373914.

[16] Saurabh Kumar et.al, "Artificial Intelligence Power Controller of Fuel CellBased DC Nanogrid", *2019 IEEE 1st International Conference on Energy, Systems and Information Processing (ICESIP 2019) : 04-06 July 2019.*

[17] M. Kotulla, J. Petrov, R. Gono, and A. Chesalkin, "Marine Solution for PEM Fuel Cells in AC or DC Grid," 2022. doi: 10.1109/EPE54603.2022.9814147.