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Energy Management and Control in Micro Grid with Hybrid Energy Storage Systems by Using PI and Flatness Theory

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Abstract - *In this paper, the control and energy management system (EMS) has been addressed for the smart isolated grid system. The proposed system consists of two sources for the production of renewable energy, solar cell (PV) and fuel cell (FC). These units work to integrate production and achieve stability, where PV is considered the primary source of production, in the case of the availability of ideal conditions from radiation and temperature, FC compensates for the lack of energy when any defect occurs in the PV unit. Two types of storage units, Battery (Bat.) and a super-capacitor (SC), were linked, each complementing the other to get a fast and long-term response. These units are linked with DC_bus by inverters. DC_bus and AC_bus were used with AC and DC loads. By using two types of control methods PID and Flatness to obtain a constant voltage For AC and DC loads, Also the PSO method was used to track the production of units PV to obtain the highest energy from the available solar radiation MPPT, where the super-capacitor SC controls the voltage of DC and AC bus. The Matlab program represented the system, and it was found that this system can be applied to isolated networks to obtain high power stability.*

Keywords — *Flatness, Fuel cell (FC), solar cell (PV), energy and management system (EMS).*

I. INTRODUCTION

Common problems facing the electrical network was the demand for electric power as the demand varies within one day to move from the peak to the valley based on the user's needs, and during the seasons where the demand varies according to the season. Hence, the electric power production companies had to build additional stations To cover peak times, which caused additional financial losses for companies producing electric energy.

Currently, electric power networks suffer from an additional problem: entering renewable energy (wind energy, solar energy) into production stations. Renewable energy plants have many advantages that were the cause of a real revolution in providing electrical energy to preserve the environment and a permanent energy source.

Photovoltaic cells were used in this system as a renewable energy source, as they are considered one of the most widespread sources of renewable energy [1]. The energy output of solar cells is affected by two main factors, temperature and radiation intensity. Any increase in temperature leads to a decrease in the voltage of photovoltaic cells with a slight increase in current. This leads to a decrease in the production of photovoltaic cells. At the same time, an increase in solar radiation leads to an increase in the cell's current. This leads to an increase in its production [2,3].

In addition to the photovoltaic cell, the fuel cell was used as a second source of energy

energy chemical units, chemical reactions lead to the release of energy. This method works through the fuel cell FC[4,5]. The fuel cell works by using saturated hydrogen when combined with oxygen produced electrical energy and water. This energy is continuous if the hydrogen source is continuous. The reactions product does not contain any harmful substances to the environment like CO_2, and hence this technology is considered environmentally friendly. The anode electrode consists of liquid or gas fuel (hydrogen gas), and the cathode is oxygen, air or chlorine [6]. The amount of energy produced depends on the size of the FC and the amount of hydrogen (the larger the hydrogen tank size, the higher the amount of energy production).

But the renewable energy has disadvantages, the most important of which is the instability of production due to the fluctuation of the energy source (sun, wind, hydrogen availably) reflected in the electric grid's performance.

This requires additional efforts in providing an alternative energy source that can be introduced into the electric grid to compensate for the shortage of renewable energy stations.

One of the most important solutions is to add energy storage units to the electrical grid, which are used to store energy in the valleys, which can be used at peak times. In addition to compensating for the lack of electric power, these units add high stability to the network.

The hybrid energy storage system (HESS) integrates two or more storage methods applied in the MG to obtain the best advantages and get rid of the defects in the different storage methods.

It is known that storage methods suffer from some negatives (Short life cycle, slow discharge, low stored energy) due to their physical nature, so it has become necessary to avoid these negatives when working in the smart grid. We note that the devices characterized by high energy are relatively slow (minutes) in responding to the request, but they have a long supply time. As for the devices' high power quickly respond to the request (seconds or less), but they suffer from a short supply period.

When combining these two types, We get a quick response and a long supply time, which achieves reliability, stability and improves the quality of the smart grid. A typical example is the combination of SC high power with high battery energy.[7]

Super-capacitor SC works to store energy in the electrostatic field, resulting from applying a constant voltage to two Surfaces representing the poles of the capacitor insulated with insulating materials [8].

These types can work at different temperatures, have little internal resistance, fast charging and discharging process, high energy density 5 wh/kg [9], average power 10 to 75 KW, long life cycle, charging cycle 10000, not affected by operation DOD, efficiency ratio Energy 95% [10], suffering from low energy density.

The battery is used with the SC to achieve their integration and avoid possible defects in the SC.

The battery is considered one of the oldest methods of storing and generating electrical energy that use chemical reactions to produce electrical energy [11], where this type represents all rechargeable batteries and flow batteries.

In the process of charging, when the electrodes of the battery are connected to an external load, the electrochemical reactions in the oxidation and reduction processes work to transfer an electron to the external load through the electric current. In the case of charging, a voltage applied to both ends of the battery operates, in contrast to the electrochemical process. It is considered one of the mature technologies at the level of scientific studies and practical applications. It has an energy density of 10 to 13 wh/kg. And the production efficiency 70% to 80%.[12], the charging time ranges from one second to 5 hours according to the battery size, technology used, and initial charge quantity in the battery. Batteries support most of the applications that need storage devices because of the flexibility in providing different capacities of power density (90 to 75 kW/m3)and energy density (75 to 800 kW/m3). [13] Algorithms PI and Flatness have been proposed to manage the source of production and storage units to achieve the required stability of the electrical network.

This paper is organized as follows: Section I Introduction, Section II systems structure. Section III system behaviour. Section IV control and management strategy, section V case study, and final conclusion in section VI.

II. Hybrid energy storage system structure

A. System Configuration.

As in figure (1), system structure consists of PV array (1STH-245-WH)15 parallel strings, with 4 modules connected in series per string, connected to DC-Bus by DC/DC boost converters. Fuel cell(FC) type(PEMFC-6kw-45dc) connect to DC-Bus by DC/DC boost converters .super capacitor (SC) and Lithium-Ion Battery(Bat) are connect to DC_Bus by DC/DC Bidirectional converters.

Convertors used to control power-sharing and maintain voltage DC_Bus and stabilized on (120V).micro grid designed to works in off-grid (islanded) .system contains variable DC_load, connected in parallel with DC_Bus without any additional device, and AC_load connect with AC_Bus. Some papers use new techniques to reduce the total harmonics distortion for different converters [14, 15,16,17,18].

PV, FC works as the power source, providing power to variable loads. Bat. SC storage units help stabilize voltage DC_Bus during loads sudden change and supply power to system, when lack of production in power supplied by PV, FC.

As shown in figure (1), power supply and storage units are connected by converters in parallel with DC_Bus. Bidirectional converters connected to SC, Bat. Works to regulate charge/discharge process, management and control fast fluctuation in voltage DC_Bus .boost convertors control power generation by PV, helping to track generation, and choose the best method to control and manage PV energy. Boost converters control power generation by FC. all converters are controlled by inner current control loops, SC control loop much faster from author loops to control voltage DC_Bus .AC_Bus connected with DC_Bus by centralized inverter.

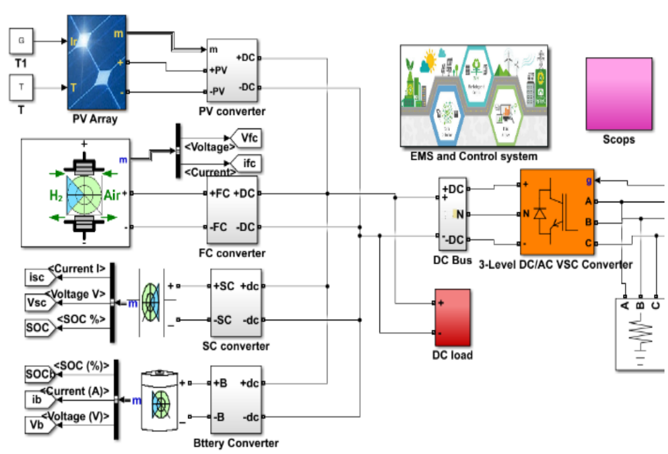

Figure (1) proposed system structure

B. Battery model.

The proposed electrical circuit of the battery model is based on the Lithium-Ion model. The dynamic properties are suitable for the proposed simulation system. The lithium-Ion battery has a high energy density, and it can satisfy long-term power demand.

Connecting the battery with the super-capacitor in the system provides high power density with high energy density, which achieves high system stability during the continuous increase in demand, and the fluctuation in demand. Figure (2) represents the Battery model.

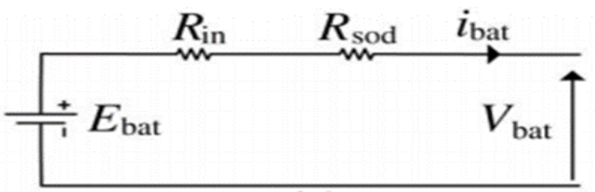

Figure (2) battery model

Where E_bat represents open-circuit voltage, i_bat represent battery current, R_sod and R_in represent internal resistor. The equations given below represent output voltage and SOC [19,20,21].

$$E = E_o - K.\frac{Q}{Q - \int it} + A.\exp(-B\int idt) \quad (1)$$

V_bat=E - iR (2)

$$SoC(t) = \frac{Q(t_o) + \int_{t_o}^{t} \alpha.i.dt}{Battery\ Rated\ capacity} \times 100 \quad (3)$$

Battery parameters 24 voltage ,rated capacity 2000Ah , initial SOC 95%,battery response time 1s ,discharge current 869.5A as show in figure (3).

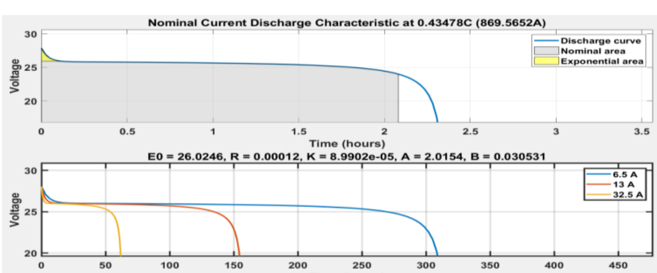

Figure (3) battery characteristic

C. Fuel Cell model.

Store energy chemically; chemical reactions lead to the release of energy.

The flow of production in these cells depends on the availability of fuel (hydrogen). As shown by the following equation:

$$2H_2 + O_2 \leftrightarrow 2H_2O + heat + electricity \quad (4)$$

Therefore, fuel cells are a controllable energy source.

Used Simulink model PEMFC 6kw-45vdc with the equivalent circuit as shown in figure (4).

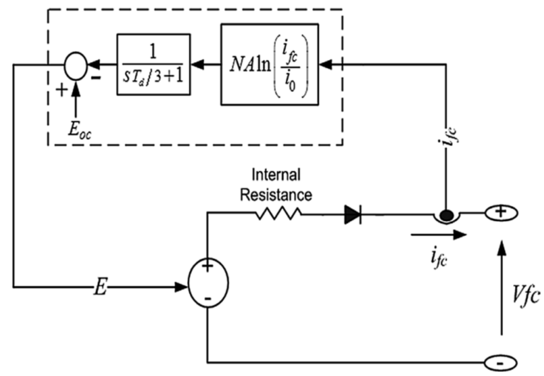

Figure (4) fuel cell model

The V-I, P-I curve for FC are in figure (5)[22,23,24,25].

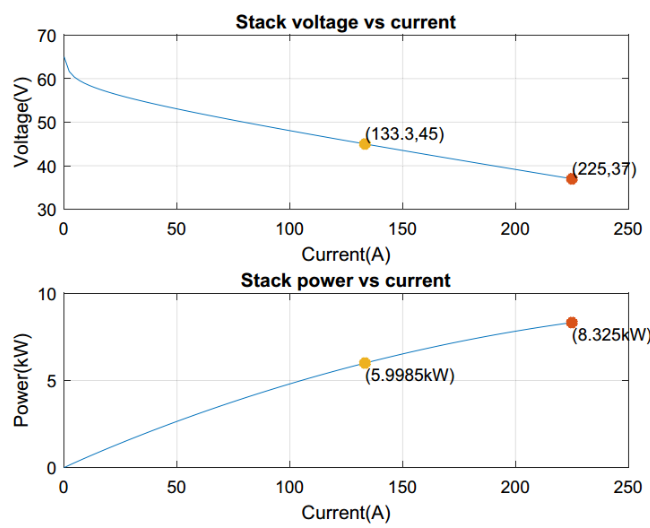

Figure (5) I-V and P-V characteristics graphs of the proposed fuel cell

The equation of FC parameters :

$$E_{oc} = K_c.E_n \quad (5)$$

$$i_o = \frac{ZFR(R_{H2} + P_{o2})}{Rh}.e^{\frac{-\Delta G}{RT}} \quad (6)$$

$$A = \frac{RT}{Z\alpha F} \quad (7)$$

These parameters are given in table (1)

Table (1) parameters for battery model

R	8.3745 j/(mol K)	z	Number of moving electrons
F	96485 As/mol	k	Boltzmann's constant 1.38×10^{-23} J/K
E_n	Nernst voltage (V)	h	Plank's constant 6.626×10^{-34} Js
α	Charge transfer coefficient	ΔG	Size of the activation barrier
P_{H_2}	Partial presser of hydrogen (atm)	T	Temperature (K)
P_{O_2}	Partial presser of oxygen (atm)	k_c	Voltage constant at nominal conditions

D. PV modelling.

Type of PV model in this thesis in Simulink environment (1soltech 1STH 245wh).

Model characteristic maximum power 244w, Vmax.ppt 30V, current max.ppt 8A with the equivalent circuit in figure (6).where I_Ph current of PV dependent on irradiation rate, I_d diode current, R_p, R_s internal resistor, V_pv voltage cell.

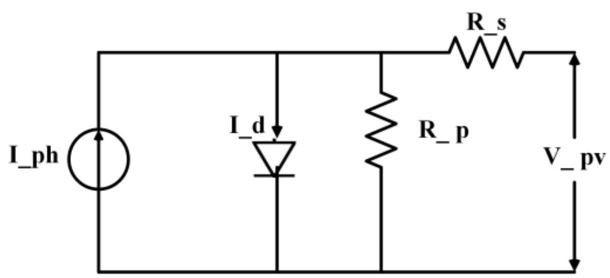

Figure (6) mathematical model of PV cell

we can find output current in the equation:

$$I = I_{ph} + I_o\left[e^{\frac{q(IR_s)}{K_B T a}} - 1\right] - \frac{(V + IR_s)}{R_p} \quad (8)$$

q charge of the electron, K_B Boltzmann constant.

$$I_{ph} = \left[I_{sc} + K\left(T - T_{ref}\right)\right]\lambda \quad (9)$$

I_{sc} short circuit current, T actual temp. ,T_{ref} reference temp., K coefficient temp., λ value of radiance kW/m2.

$$I = N_p I_{ph} - N_p I_o\left[e^{\frac{V + I(N_s N_p)R_s}{N_s a V_{th}}} - 1\right] - \frac{V + I\left(\frac{N_s}{N_p}\right)R_s}{\left(\frac{N_s}{N_p}\right)R_p} \quad (10)$$

I_{ph} model current, R_s series resistance, R_p parallel resistance, a ideality factor, I_o saturation current .[19,20,25,26].

E. Super /ultracapacitor model.

SC model in Simulink, Rated capacitance 80 F, Rated voltage 48 v, Ioc. 10 A.

Charge characteristics show in figure (7).

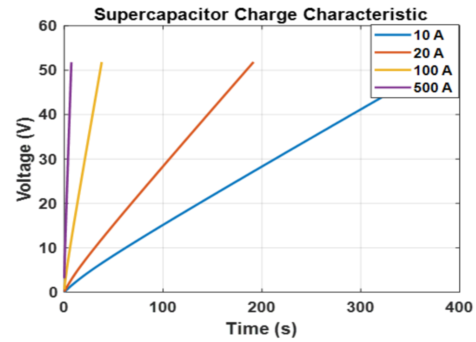

Figure (7) super-capacitor charge curve

To control voltage, DC_bus must be kept SC SoC at 25%, To be able to absorb the excess energy in the DC_bus.SC high power density, high cycle life, fast charging time, long service life, high current discharging. Figure (8) show the equivalent circuit for the SC module**.**

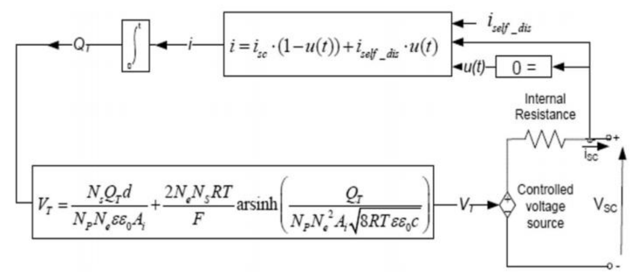

Figure (8) the equivalent circuit of the SC module

The equation voltage of SC is:

$$V_{sc} = E_{SC} - \frac{1}{c}.\int_o^t i_{sc}dt - i_{sc}.R_{ESR} \quad (11)$$

V_{sc} terminal voltage, R_{ESR} equivalent resistance, E_{SC} voltage for the main capacitor, i_{sc} current charge / discharge.

The equation for SoC SC.

$$SoC_{sc} = \frac{V_{sc}}{E_{full}} \quad (12)$$

when E_{full} SC fully charge.

As show in simple circuit (9)[261,27,28,29].

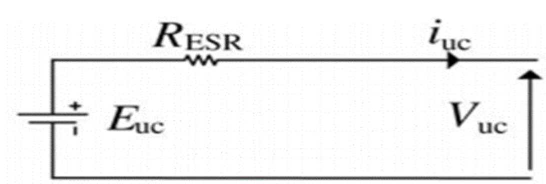

Figure (9) simple circuit for SC

F. Load modelling.

Two dynamic loads were proposed, DC_load, AC_load.
The equation for two loads :

$$P_{Ac\_load} = i_{AC\_load}.V_{AC\_bus} \quad (13)$$

$$P_{DC\_load} = i_{DC\_load}.V_{DC\_bus} \quad (14)$$

III. System Behaviour Model.

Set reference point for power PV, FC, Bat and SC. P_{PVREF},P_{FCREF},P_{BatREF},P_{SCREF} respectively.
It can be found power reference from these equations:

$$P_{PVREF} = P_{PV} = v_{PV} \times i_{PVREF} = v_{PV} \times i_{PV} \quad (15)$$

$$P_{FCREF} = P_{FC} = v_{FC} \times i_{FCREF} = v_{FC} \times i_{FC} \quad (16)$$

$$P_{BatREF} = P_{Bat} = v_{Bat} \times i_{BatREF} = v_{Bat} \times i_{Bat} \quad (17)$$

$$P_{SCREF} = P_{SC} = v_{SC} \times i_{SCREF} = v_{SC} \times i_{SC} \quad (18)$$

The main objective for the management system, keep DC_bus voltage at set point 120 voltage.
To achieve that. Must control DC_bus through the SC, by (charge/discharge) process to and from DC_bus.
The equation for DC_bus capacitive energy :

$$y_{Bus} = \frac{1}{2} C_{Bus} \times v_{Bus}^2 \quad (19)$$

SC capacitive energy :

$$y_{SC} = \frac{1}{2} C_{SC} \times v_{SC}^2 \quad (20)$$

DC_bus capacitive energy can be written by the differential equation :

$$y_{BUS} = p_{PVo} + p_{FCo} + p_{Bato} + p_{SCo} - p_{load} \quad (21)$$

Where
p_{PVo} ,p_{FCo} ,p_{Bato} ,p_{SCo} power output from PV, FC, Bat, SC, converter, respectively. with static losses r_{PV} for PV, static losses r_{FC} for FC, static losses r_{Bat} for battery, static losses r_{SC} for SC.

$$p_{PVo} = p_{PVo} - r_{PV} \times (\frac{p_{PV}}{v_{PV}})^2 \quad (22)$$

$$p_{FCo} = p_{FCo} - r_{FC} \times (\frac{p_{FC}}{v_{FC}})^2 \quad (23)$$

$$p_{Bato} = p_{Bato} - r_{Bat} \times (\frac{p_{Bat}}{v_{Bat}})^2 \quad (24)$$

$$p_{SCo} = p_{SCo} - r_{SC} \times (\frac{p_{SC}}{v_{SC}})^2 \quad (25)$$

Power for the load can be written by using equation(19)

$$p_{load} = v_{Bus} + i_{load} = \sqrt{\frac{2y_{Bus}}{C_{Bus}}} \times i_{load} \quad (26)$$

IV. Control And Management Strategy

Three variables must be controlled to control all systems.

1. DC_bus (energy y_{Bus} or voltage v_{Bus}) the most crucial variable.
2. SC (energy y_{SC} or voltage v_{PV}).
3. Battery (state of charge (SoC) or energy y_{Bat}).

We can achieve this through these variables.P_{PVREF},P_{FCREF},P_{BatREF},P_{SCREF} where, SC control DC_bus because SC fast energy source by supply and Drawing power from the DC grid to stabilise DC_bus battery control and charging SC, FC control and charging the battery.

A. Control PV Converter.

PV model operating in Maximum PowerPoint Tracking (MPPT) by using particle swarm optimization (PSO) algorithm as shown in figure(10) flowchart to achieve MPPT[30].

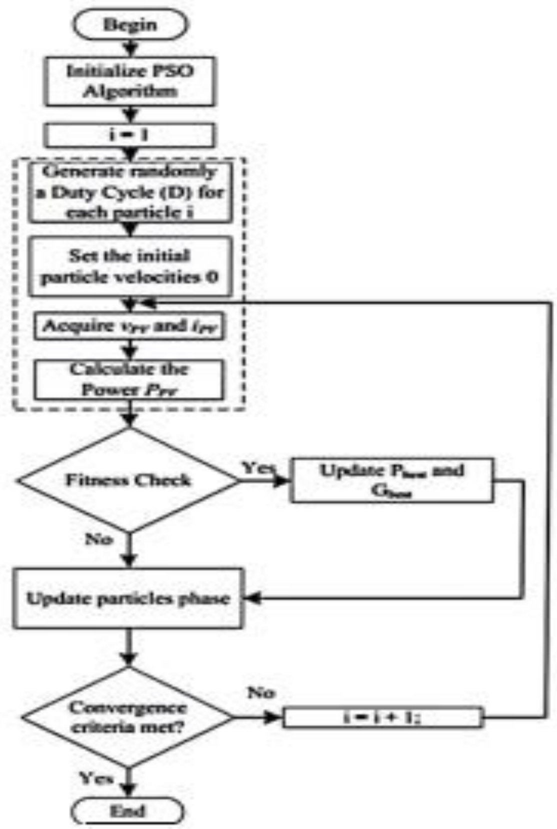

Figure (10) PSO based MPPT flowchart

Power supply generation from PV, FC must be made up of all loads, equation of total power :

$$p_{Gen} = p_{FCo} + p_{PVo} \quad (27)$$

by replacing in equation (21)

$$y_{BUS} = p_{Gen} + p_{Bato} + p_{SCo} - p_{load} \quad (28)$$

The difference between power generation and power demand is used to charge storage devices (Bat, SC), and shortage of product supply from the storage device (Bat, SC) to loads.

$$p_{Gen} = y_{BUS} + p_{load} - p_{Bato} - p_{SCo} \quad (29)$$

B. DC_Bus Voltage control.

To control (regulate)DC_bus voltage v_{Bus} using PID theory figure(11).

$$P_{Bus} = y'_{Bus} = \left(k_{pbus} + \frac{k_{Ibus}}{s}\right) \times (y_{Bus} - y_{Bus_{Ref}}) \quad (30)$$

k_{pbus} ,k_{Ibus} controller parameter

$$I_{SC\_Ref} = P_{Bus} \div V_{SC} \tag{31}$$

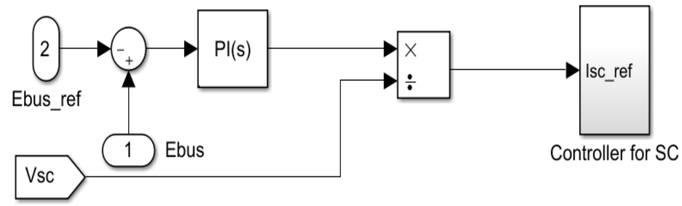

Figure (11) voltage DC_bus controller by using the PI method

To produce controller parameter for SC invertor (d_sc) figure (12).

$$d\_sc = (I_{SC} - I_{sc\_Ref})\left(k_{i3} + \frac{k_{i2}}{s}\right) \tag{32}$$

Where :

$k_{i3} = 2.\tau.w_n$, $k_{i2} = w_n^2$ τ = dumping factor = 0.7

$w_{n=2\pi f=314}$

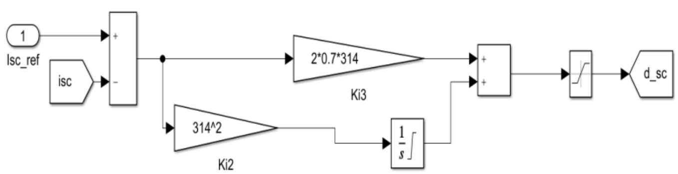

Figure (12) controller reference for SC

C. Charging SC.

Used battery model to charge SC, consideration the y_{Bus} as a constant, and there are no losses in convertors, the equation (21) can be rewritten in a new form.

$$p_{SC} + p_{load} = p_{PV} + p_{FC} + p_{Bat} \tag{33}$$

By using proportional (P) and integration (I) control, it can generate SC power demand (SC_{SCDEM}):

$$p_{SCDEM} = \left(k_{psc} + \frac{k_{Isc}}{s}\right) \times (v_{SCREF} - v_{SC}) \tag{34}$$

Where K_{ISC} ,K_{pSC}represented control parameter .there for p_{SCDEM} same $p_{BatEst.}$, to protect the battery from high charge and discharge current, it must be limited by two values (I_{BatCh})(negative value), (I_{BatDis})(positive value), by using minimum and maximum functions. value result (p_{BatSAT}) to optimize battery lifetime .this limit in power (current) slop suitable to increase battery lifetime .to do this, used first-order filter for battery power dynamics figure (13).

$$p_{BatREF}(t) = p_{BatSAT}(t) \times \left(1 - e^{\frac{1}{\tau 1}}\right) \tag{35}$$

$\tau 1$ is the regulation parameter.

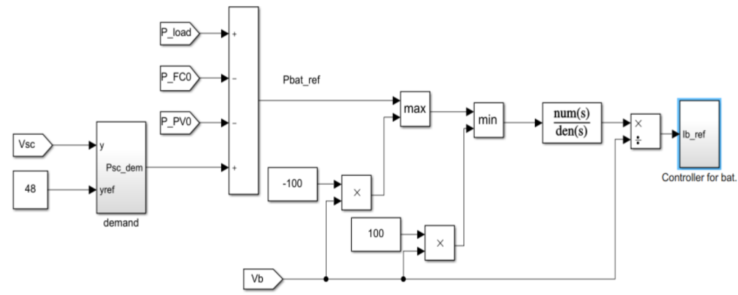

figure (13) charge SC controller by using the battery model

D. Charging Battery

To control Battery energy, using flatness theory, the parameter of flatness, u input variable, y output variable, x state variable figure (14).

$y = E_{Bat}$, $u = p_{Total\_REF}$, $x = v_{Bat}$

From(19),v_{bus} can be represented as

$$v_{bus} = \sqrt{\frac{2E_{bus}}{C_{Bus}}} \tag{36}$$

$$E_{Bat} = V_{Bat} \times R = \varphi(y) \tag{37}$$

$$E_{Bat\_Ref} = V_{Bat\_Ref} \times R \tag{38}$$

Where R= rated capacity for battery (Ah).

$$y' = (E_{bat} - E_{Bat_{Ref}})\left(kp_{bat} + \frac{ki_{bat}}{s}\right) \tag{39}$$

From (21)(26) , u total power reference can calculated from y, (time derivative).

$$u = 2p_{Gmax}\left[1 - \sqrt{1 - \left(\frac{y^{\cdot} + \sqrt{\frac{2E_{bus}}{C_{Bus}}} \times i_{load} + p_{SCo}}{p_{Gmax}}\right)}\right] \tag{40}$$

$u = \omega(y, y^{\cdot}) = p_{Total\_REF}$

Where p_{Gmax} power from FC and PV (limit maximum power)

$$p_{Gmax} = p_{FCmax} + p_{pvmax} \tag{41}$$

$$p_{FCmax} = \frac{v_{FC}^2}{4r_{FC}} \tag{42}$$

$$p_{pvmax} = \frac{v_{pv}^2}{4r_{pv}} \tag{43}$$

Total power generation in DC microgrid consist of PV and FC, must put reference for total power (p_{Total}).

$$p_{FC\_REF} = p_{Total\_REF} - p_{pvo} \tag{44}$$

p_{FC} limit between max. p_{FCmax} and min p_{FCmin} (her set to 0 W) .

p_{PV} limit between $p_{PV\,max}$(max. power point tracking (MPPT)) and min $p_{Pv\,min}$(her set to 0 w). The main variable in the power equation is (PV), the difference between p_{Total} and $p_{PVReF}$is the FC power demand p_{FCDEM} to achieve that using the second-order filter.

$$p_{FCREF}(t) = p_{FCDEM}(t) \times \left(1 - e^{\frac{-t}{\tau 2}} - \frac{t}{\tau 2} e^{\frac{-t}{\tau 2}}\right) \qquad (45)$$

$\tau 2$ control parameter .

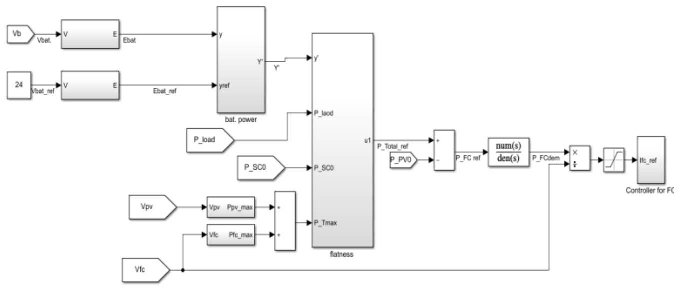

Figure (14) charging battery by FC model using flatness theory

V. Case Study

In this part, two cases are represented to show the control cases for the different parameters (voltage DC_bus, SC, Bat.). In the case of a fixed load with a change in solar radiation. In the second case, the load varies with the stability of the radiation. Changes in the behaviour of each part of the system are observed, including (PV, FC, SC, Bat.).

Case A: constant load DC=3600 w ,constant load AC =5000w with different radiation for PV cell 500 between 0 to 0.9s , 800 between 0.9s to 1.4s , 1000 between 1.4s to 2 s. figure(15).

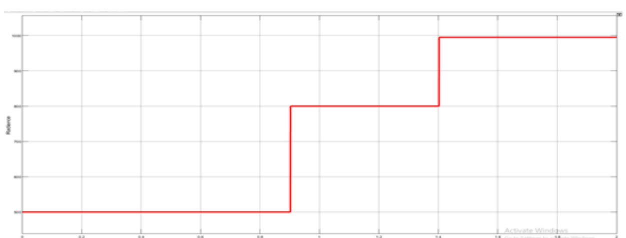

Figure (15) change radiation

In figure (16), we see the DC_bus voltage stable in 120 V, in 0.9s,1.4s increase radiation due to increase in power generator by PV, The SC absorbs the sudden change in PV power generation, and converts it into stored energy.

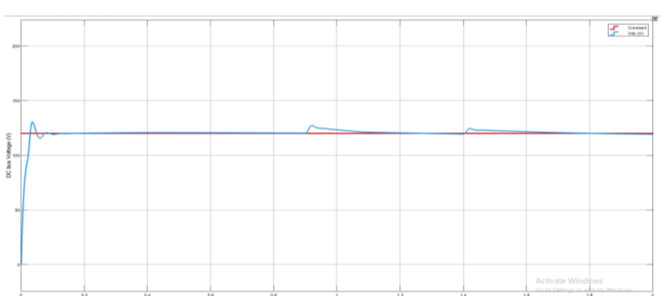

Figure (16) voltage DC_bus constant load variable radiation

In figure (17), from 0 s to 0.9 s Ppv less than P load AC and DC. SC and FC compensate for the shortage of production. At 0.9s increase in power generation by PV, SC absorbs power by starting charging, FC production decreases .at 1.4s increase in power generation by PV which covers power loads, FC generation became zero, The sudden increase in production from PV is converted into stored energy by charging SC. And we can see the battery become charging.

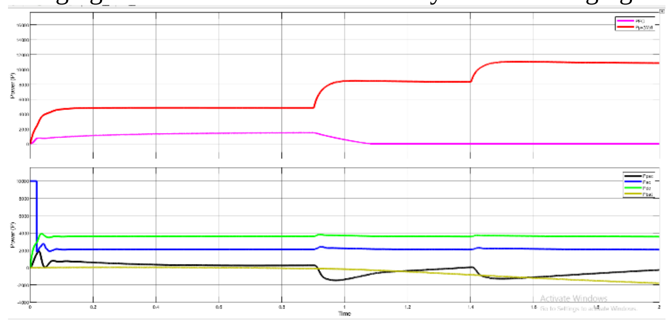

Figure (17) Ppv , Pfc , Pac ,Pdc , Pbat ,Psc with constant load variable radiation

Figure (18) stat of charging SOC and discharging of SC, power with negative value main SC charging energy, and when positive value SC discharging energy. We notice that when the output power from PV is less than load power, SC compensates for the shortage with the help of FC via the discharging operation, so the value of SOC% starts decreasing. Higher output from the unit PV and the discharge process of SC became less until the output PV is greater than the power loads, SC begins to charge.

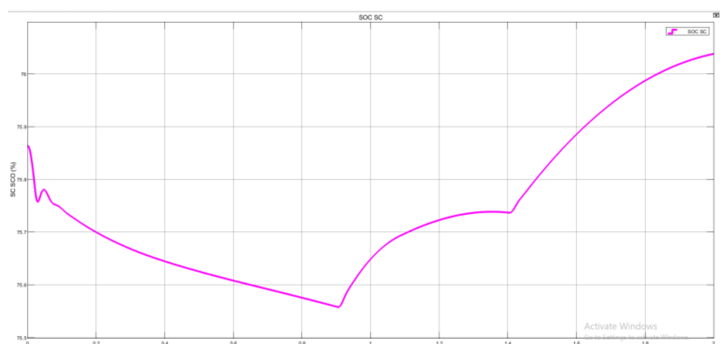

Figure (18) SC SOC% with constant load variable radiation

Figure (19) battery SOC% ,SOC constant until 1.4s ,battery start charging

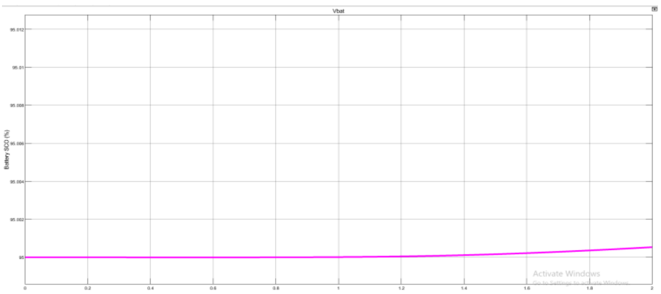

Figure (19) Battery SOC% with constant load variable radiation

Case B: different load with constant radiance.
Radiance = 800 , DC loads 2400 w between 0 s to 0.5 s , 3600 w between 0.5 s to 1.2 s , 1800 w between 1.2 s to 2 s ,Ac load 5000 w.
In figure (20), we see the DC_bus voltage stable in 120 V, in 0.5s,1.2s increase load from 2400 w to 3600w due to sudden change in power generator by PV, The SC discharge energy to the bus, in 1.2s load decrease from 3600 w to 1800w the sudden change in PV power generation, SC begin to charge to absorbs energy, and converts it into stored energy.

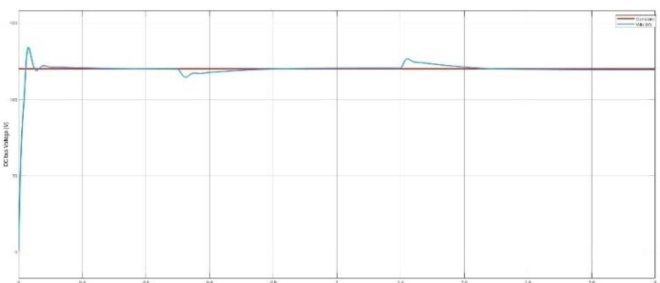

Figure (20) voltage DC_bus constant radiation variable loads

In figure (21), from 0 s to 0.5 s power PV less than Power load AC and DC, the shortage of production is compensated by SC and FC. at 0.5 s load DC increase from 2400 w to 3600 w, with constant radiation, the power shortage increase. Therefore, the deficiency is compensated by FC and SC .at 1.2 DC load decrease from 3600 w to 1800 w, power PV with power SC became greater than power load, power FC became zero. SC absorbs sudden change in power by charging process. And then go back to the discharge process to compensate for leakages power.

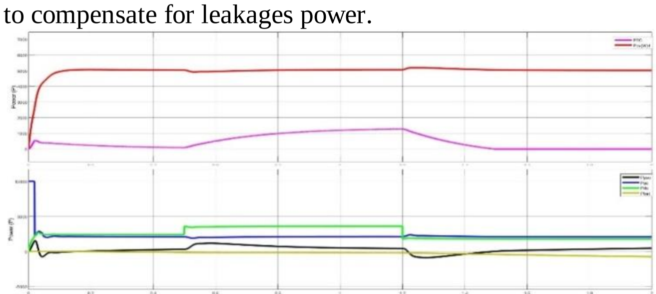

Figure (21) Ppv , Pfc , Pac ,Pdc , Pbat ,Psc with constant radiation variable loads.

Figure (22) state of charging SOC and discharging of SC, power with negative value main SC charging energy, and when positive value SC discharging energy. We notice that when the output power from PV is less than load power, SC compensates for the shortage with the help of FC via the discharging operation, so the value of SOC% starts decreasing. At 0.5 s when increase load, increase discharge process of SC . at 1.2 s decrease in load value but the SC continue to discharge.

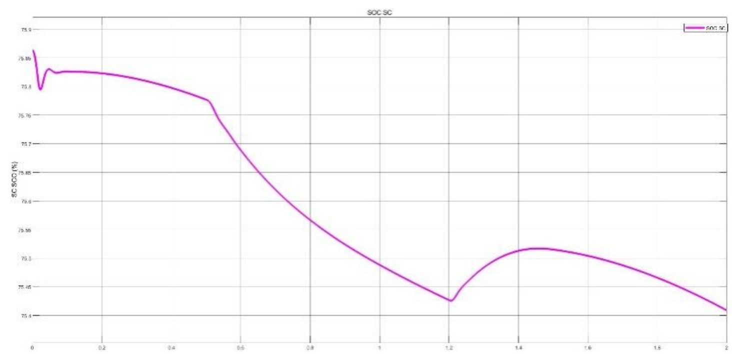

Figure (22) SC SOC% with constant radiation variable loads

battery SOC% ,SOC constant until 1.2s ,battery start charging.

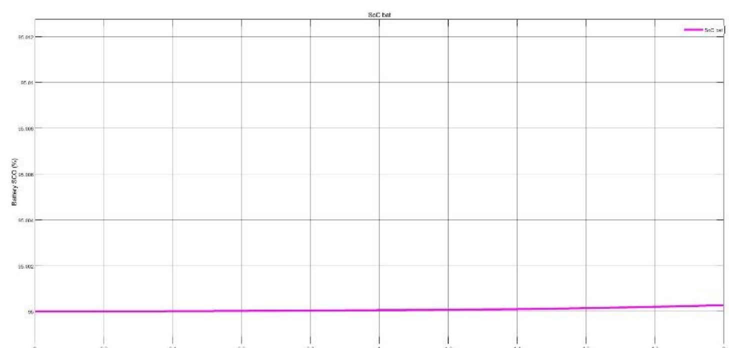

Figure (23) Battery SOC% with constant radiation variable load

VI. CONCLUSION

This research works with energy control and management for smart microgrid systems in islanding mode. This system consists of two supply sources of renewable energy PV and FC, with two models of energy storage system Battery and super-capacitor, linked with DC_bus and AC_bus, with different loads and variable radiation, by using two theories PID and nonlinear differential flatness, this theory proved its ability to control voltage stability of DC_bus and AC_bus, And continuity of supply for electrical energy from generation source and storage model to the loads, especially during the sudden change in loads and the difference in radiation. The system was designed, and the results were obtained using the Matlab Simulink program.

Table 2
System Parameters

$V_{Bus\ REF}$	120	V
$V_{SC\ REF}$	48	V
$V_{Bat\ REF}$	24	V
$V_{FC\ REF}$	45	V
V_{PV}	120	V
SOC_{Bat}	95%	
C_{SC}	80	F
C_{Bus}	100	μF
KP_{Bus}	250	
KI_{Bus}	600	
KI_{SC}	100	
KP_{SC}	3	
τ_1	1	s
KP_{Bat}	60	
KI_{Bat}	150	
r_{FC}	0.1	Ω
r_{PV}	0.01	Ω
r_{SC}	0.1	Ω
r_{Bat}	0.01	Ω

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