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Decentralized power management of PV/battery hybrid units in Islanded Microgrids SYSTEMS

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ABSTRACT: In this paper, a control strategy is developed to achieve fully autonomous power management of multiple PV/battery hybrid units in islanded microgrids. Also, the developed strategy has the ability to autonomously coordinate with dispatchable droop controlled units. The power supplied by the hybrid units is autonomously determined based on the available PV power from all hybrid units, the total generation capacity of the available dispatchable units, the total load demand, and the SOC of all batteries in the microgrid. In addition to maintaining the power balance in the microgrid, the decentralized coordination scheme prioritizes charging the microgrid batteries with lower SOC. Also, the control strategy enables the hybrid units to import power from other units to support charging their batteries. These features are achieved by employing the proposed multi-segment adaptive power/frequency (P/f) characteristics in the hybrid unit controllers. Since the strategy is based solely on the local voltage controllers, neither a central EMS nor communications among different units are required.

Keywords: Microgrid, droop control, PV, battery storage.

I. INTRODUCTION

The increasing demand of energy consumption and raising environmental pressure on the traditional concentrated power generation based on fossil fuel, coal and nuclear, is cherishing a near future of deploying cleaner and more efficient energy exploit ways. Although the manner of utilizing clean energy varies, the society and research has been gradually to embrace the new form of power generation that utilizes the graphically dispersed and clean generator – distributed generation (DG). Compared to the conventional top-down electricity infrastructure, the DG utilizes locally installed and relatively small capacity electrical generation, which can include renewable energy resources for example of solar and wind energy, small hydro power and biomass etc., and also can comprise some non-renewable sources such as small size gas and diesel turbines. Therefore, the DG not necessary refers to employ complete renewable energy source. Rather, it indicates a system structure that the downstream or end of power system utility not only passively act as power consumer, but also actively take the role as power producer. The DG facility brings the advantages such as i) flexibly utilization of the downstream locally installed energy sources (especially renewable energy sources), ii) convenient storing energy in a dispersed way and thus can be realized in a lower scaled capacity, iii) can be used to perform peak-shaving action in terms of economic benefits.

This end-to-end manner of power generation and consumption, similar with the internet structure, naturally brings the promise of smart grid (SG) round the corner together with the advanced communication technology. However, due to the inherent limitation and strict requirement of power system, the massive application of DG facility raises the following challenge: i) The power electronic device interfaced DG units usually does not contributes to the frequency inertia, thus their plug-and-play characteristic when the electrical faults happens can introduce the frequency instability to upstream power system. ii) The change from traditional unidirectional to bidirectional power flow of these casually located DG units takes the difficulty of power dispatch and device protection. iii) The large amount of dispersed power electronic equipment and passive components bring new power quality issue that harmonic can penetrate among the network. Therefore, in order to maintain the merit of flexibly utilization of these distributed resources, and to alleviate the potential harm to the traditional power system by totally dispersed DG infrastructure, researchers are seeking new ways that can form these DG units into a smaller size of grid which can sustain the power consumption by itself, and at the same time is able to interact with other small grids and upstream grid, by means of energy management systems. Hence the concept of Microgrid is proposed and widely investigated in recent years.

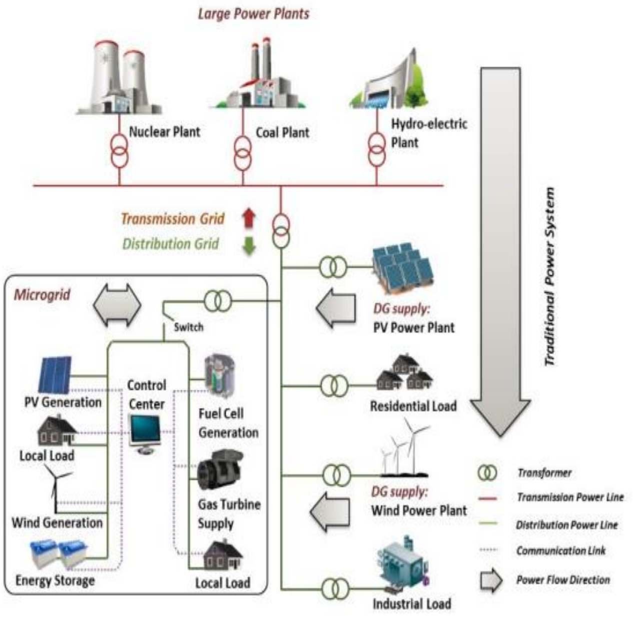


Figure1. System scheme integrated by traditional power generation, DG facility and Microgrid paradigm.

Microgrid groups the DG units together with distributed storage (DS) system, local (electrical and/or thermal) loads usually comprises two modes of operation: islanded mode and grid-connected mode. In general, the Microgrid has only one point of common oupling (PCC) to the external system. Therefore, instead of using massive and various grid-connected interfaces of DG units, the Microgrid can be considered as an integration of these DG units, and acts as a controllable cell to import/export power from the view point of host main grid. Compared to the DG facility, Microgrid has potential to optimize utilization of DG units by complementing the advantage of different DG sources, and meanwhile reduce the risk of fault when connecting dispersed DG units to the main grid separately. Furthermore, when there is an occurrence of fault on the host main power system, the PCC is disconnected so that the Microgrid operates as an autonomous system to sustain the power balance between eneration and consumption by itself .

This environment of power balance is achieved by means of energy management system (EMS) and designing proper control strategies among DG, DS and local loads. Due to this convenient power supply manner which can be exempt from being interacted with main grid electrical status, the islanded Microgrid operation is becoming a mainstream for the remote onsite microgrid projects nowadays. In these islanded Microgrid applications such as avionic, marine and rural areas, the AC microgrids are still presently dominant due to the intrinsic characteristic of traditional distribution system. However, with the proliferation of photovoltaic (PV) generation, and raising attractiveness of some nature DC source power supply such as fuel cells, the DC Microgrids witness fast growth in recent years. Besides reducing power conversion stages, DC grids also bring the advantages as simplifying complex control strategies used for synchronization, power quality issues taken by AC grids. As well as the circuits of modern electrical equipment requires nature DC power supply, the application of DC

Microgrids can be seen in the scenarios such as charging plug-in hybrid electric vehicles, datacom centers and future building electrical systems.

The simplest solar cell model consists of a diode and a current source connected in parallel as shown in Fig. 2.1 The current source is directly proportional to the solar radiation while the diode represents the p-n junction of a solar cell. Equations representing the ideal solar cell model can be represented in terms of current density as shown in (2.1) or current as shown in (2.2).

$$J = J_{sc} - J_0\left(e^{\frac{V}{V_T}} - 1\right)$$ -------------------------

-(2.1)

$$I = I_{sc} - I_0\left(e^{\frac{V}{V_T}} - 1\right)$$ -----------------------

-(2.2)

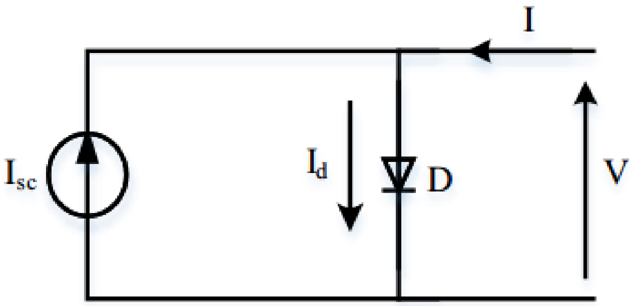


Fig. 2.1: Simple physical model of solar cells

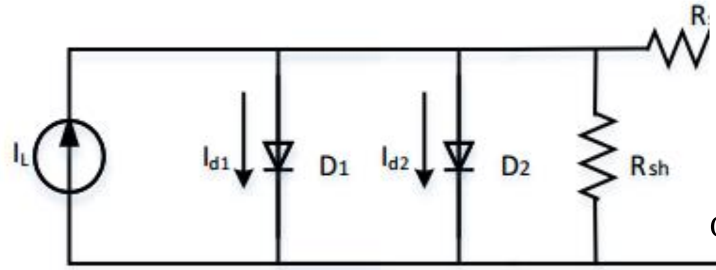


Fig. 2.2: General physical model of solar cells

where J is the photocurrent density ($A=m^2$), Jsc is the short-circuit current density ($A=m^2$), I is the photocurrent (A), I_0 is the reverse saturation current (A), V is the diode voltage (V), VT is thermal voltage (VT = 25.7 mV at 25°C).

The currents Isc and I_0 relate to their current densities Jsc and J_0 as follows:

I_{sc} = AJsc;

I_0 = AJ0 ------------(2.3)

where A is the total area of the devices excluding the metal covered area.The more accurate model of a solar cell, the general model, consists of a current source, two diodes connected in parallel, one shunt resistance and one series resistance shown in Fig. 2.3. The relationship between current and voltage for the general model is given in (2.4).

$$I = I_L - I_{01}\left(e^{\frac{V+IR_s}{n_1V_T}} - 1\right) - I_{02}\left(e^{\frac{V+IR_s}{n_2V_T}} -\right.$$

-----(2.4)

where I_L is the photo-generated current (A), I_{01} is the reverse saturation current of the first diode (A), I_{02} is the reverse saturation current of the second diode (A), n1 is the quality factor of the first diode, n2 is the quality factor of the second diode, Rs is the series resistance, and Rsh is the shunt resistance.

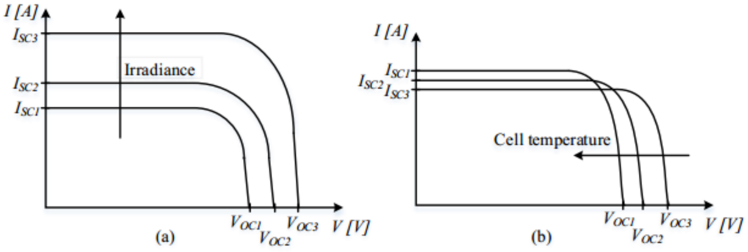


Fig. 2.3: I-V Characteristics of solar cells

General characteristics of solar cells represented by models in Figs. 2.1 and 2.2 are shown in Fig. 2.3. Fig. 2.3.a relates irradiance to the short circuit current and open circuit voltage of the solar cell.

The increasing of irradiance leads to the increasing of the open circuit voltage logarithmically and the increasing of the short circuit current linearly. The arrow direction shows the increasing of irradiance. The influence of the cell temperature on the I-V characteristics is illustrated in Fig.2.3b.The increasing of the cell temperature significantly reduces the open circuit voltage while slightly increases the short circuit current.

Single Solar Cell Model

Simulations of the solar cell behavior for changing temperature and irradiance conditions are required for the purpose of modeling photovoltaic systems. The best way to simulate this behavior is by using a behavioral model. This model assumes that the short circuit current has two main components. The first component relates to irradiance, G, while the second component is function of cell temperature, T_{cell}. The equation for short circuit current is given by:

$$I_{sc} = \frac{J_{scr} A}{1000} G + \frac{dJ_{sc}}{dT} (T_{cell} - T_r)$$ --------(2.5)

where Isc is the short circuit current (A), Jscr is the reference short circuit current density (A/m^2), dJ_{sc} /dT is the temperature coefficient of short circuit current (A/^{o}C), and Tr is the reference temperature which is usually considered 25^{o}C .

The diode component is represented by:

$$I_d = \frac{I_{sc}}{e^{\frac{V_{0C}}{V_T}}} \left((e^{\frac{V}{V_T}} - 1 \right)$$ ------------------------(2.6)

The cell temperature is derived from the NOCT (nominal operating conditions temperature) which is the temperature of the cell at 800 W/m^2 of irradiance and 20^{o}C of ambient temperature, Ta. That is

$$T_{cell} - T_a = \frac{NOCT - 20}{800} G$$ -----------------------(2.7)

The series resistance is derived as follows:

$$R_s = \frac{V_{oc}}{I_{sc}} - \frac{P_{max}}{FF_0 I_{sc}^2}$$ -----------------------------(2.8)

in which

$$FF_0 = \frac{v_{oc} - ln(v_{oc} + 0.72)}{1 + v_{oc}}$$ ----------------(2.9)

and

$$v_{oc} = \frac{V_{oc}}{V_T}$$ ---------------------------------------(2.10)

where Pmax is the maximum power (W), F F_0 is the fill factor under ideal conditions, v_{oc} is the normalized value of the open circuit voltage (V).

The current and voltage for the maximum power point (MPP) is given by:

$$I_m = I_{mr} \frac{G}{G_r} + Ax \frac{deltaJ_{sc}}{deltaT} (T_{cell} - T_r),$$

$$V_m = V_T ln \left((1 + \frac{I_{sc} - I_m}{I_{sc}} (e \frac{v_{oc}}{V_T} - 1) \right) - I_m R_s$$ -----(2.11)

where Im is the MPP current (A), Imr is the reference MPP current (A), Gr is the reference irradiance (W/m^2), Vm is the MPP voltage (V).

The behavioral model derived above is shown in Fig. 2.4. The upper figure shows the schematic form of the model consisting of the parameters derived in previous equations. The lower figure shows the parameter names for all terminals of the model.

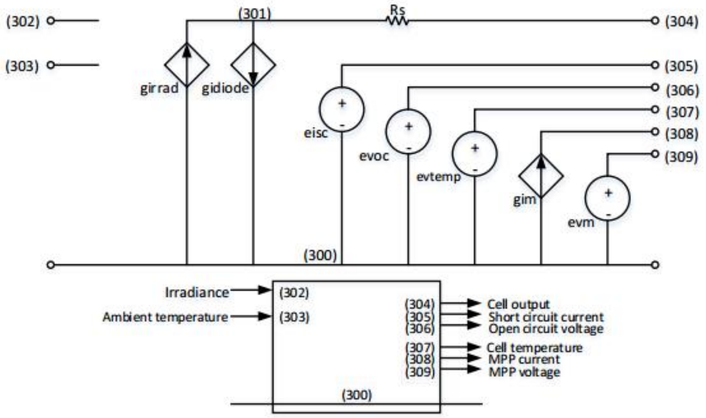


Fig. 2.4: Schematic and block diagram of the solar cell behavioral model

PV Module Model

A photovoltaic module consists of solar cells connected in series and in parallel. The connection of solar cells in a photovoltaic module is shown in Fig. 2.5. The behavioral model of a photovoltaic module is similar to the model for a solar cell. The series connection of solar cells in a photovoltaic module increases the voltage, while the parallel connection increases the current.

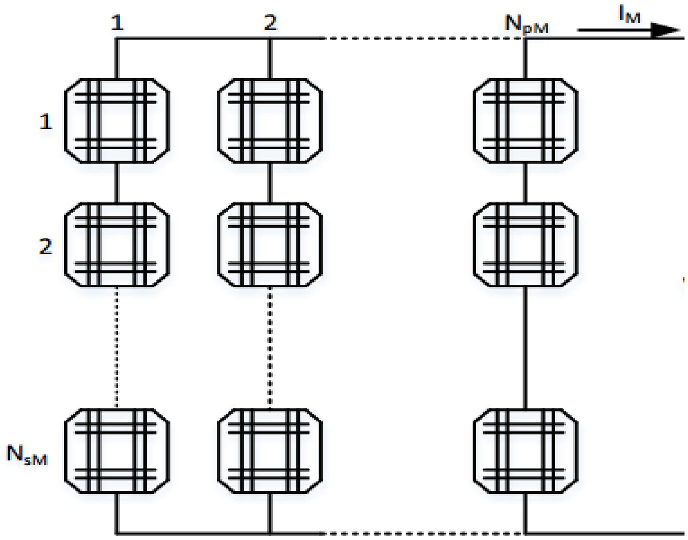


Fig. 2.5: Connection of solar cells in a photovoltaic module

The equations below are derived based on the equations for a solar cell:

$$I_{scM} = N_{pM} I_{sc},$$

$$V_{ocM} = N_{sM} V_{oc},$$

$$I_{mM} = N_{pM} I_{m},$$

$$V_{nM} = N_{sM} V_{m},$$

$$R_{sM} = \frac{N_{sM}}{N_{pM}} R_{s}. \quad \text{---------------(2.12)}$$

where the subscript M means module, NsM is the number of cells connected in series,NpM is the number of cells connected in parallel, IscM is the short-circuit current of a PV module (A), VocM is the open-circuit voltage of a PV module (V), ImM is the MPP current of a PV module (A), VmM is the MPP voltage of a PV module (V) and RsM is the series resistance of a PV module.

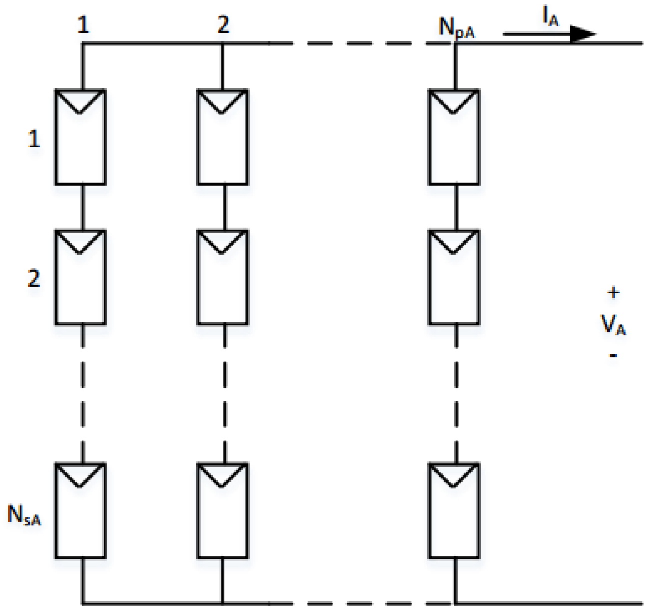


Fig. 2.6 Connection of photovoltaic modules in a photovoltaic array.

PV Array Model

Similar to the relationship between a photovoltaic module and solar cells, a photovoltaic array consists of photovoltaic modules connected in series and in parallel as shown in Fig. 2.6. The behavioral model of a photovoltaic array is very similar to the model of a solar cell or a photovoltaic module. Instead of using index M, the model of a photovoltaic array uses index A that stands for array.

The relationships between array and module currents and voltages are given below:

$$I_{scA} = N_{pA} I_{scM} = N_{pM} N_{pA} I_{sc},$$

$$V_{ocA} = N_{sA} V_{ocM} = N_{sM} N_{sA} V_{oc},$$

$$I_{mA} = N_{pA} I_{mM} = N_{pM} N_{pA} I_{m},$$

$$V_{mA} = N_{sA} V_{mM} = N_{sM} N_{sA} V_{m},$$

$$R_{sA} = \frac{N_{sA}}{N_{pA}} R_{sM} = \frac{N_{sM} N_{sA}}{N_{pM} N_{pA}} R_{s}.$$

------(2.13)

Maximum Power Point Tracking

The amount of power generated by a PV module depends on irradiance and ambient temperature. The I-V and P-V characteristic curves indicate the maximum power point (MPP) at which maximum possible power is available. The MPP is not static due to its dependency on atmospheric factors, irradiance and temperature. Hence, a technique called a maximum power point tracking (MPPT) is used to utilize the photovoltaic power effectively. The basic principle of the MPPT is described in Fig. 2.7. The dc-dc converter is incorporated with an MPPT algorithm to ensure that the maximum power is delivered to the loads. The arrows on the P-V curve indicate the MPP is approached from both sides in order to track the exact point.

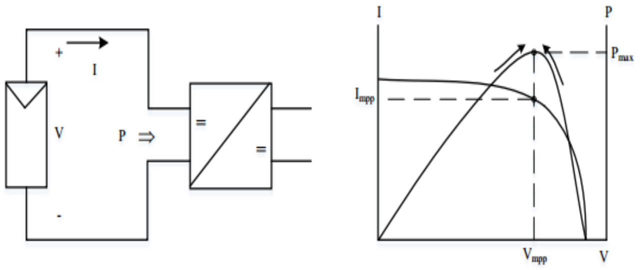


Fig. 2.7: Basic principle of MPPT.

The purpose of the MPPT algorithm is to follow the MPP as it changes with the ambient operating conditions of the PV generation system. In order to do such tracking, the terminal voltage of the PV array is manipulated. Many algorithms have been proposed for the MPPT application. Some widely adopted algorithms include: the Constant Voltage Method, the NonLinear Function Solution Method, the Perturbation & Observation or Hill Climbing Method and the Incremental Conductance Method. The model implemented in this work is based on the Incremental Conductance Method algorithm because it is widely accepted as being efficient without incurring excessive computational burdens.

EXISTING METHOD

- The existing method describes the droop control concept is widely adopted in the literature due to its inherent decentralized nature, which enables the potential plug-and-play operation. Therefore, the ability of the PV and battery systems to coordinate with droop controlled units is considered crucial for deploying PV and battery systems in widely adopted droop controlled microgrids.

- A control strategy is proposed in to provide autonomous power management of PV units in droop controlled islanded micro grids however, management of battery storage is not considered in the system.

Drawbacks of existing method

- The ability of the PV and battery systems to coordinate with droop controlled units is considered crucial for deploying PV and battery systems in widely adopted droop controlled microgrids

Proposed method

- The proposed method proposes a control strategy for PV/battery hybrid units to achieve fully decentralized power management in islanded microgrids.

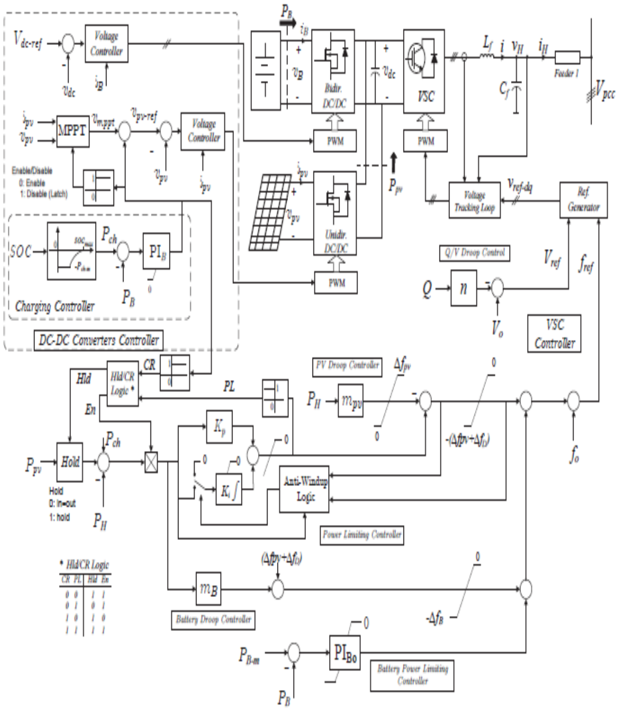
- The developed strategy provides comprehensive power management that overcomes the limited applicability, and transient drawbacks, of the above mentioned existing strategies. It can autonomously handle multiple PV/battery systems, and has the ability to coordinate with dispatchable droop controlled units (if any are available) in the microgrid.

- This is achieved through adopting the proposed adaptive multi-segment P=f characteristics. These proposed multi-segment characteristics, along with their multi-loop control implementation, result in smooth transitions among the control objectives.

Advantages of proposed method

- It can autonomously handle multiple PV/battery systems, and has the ability to coordinate with dispatchable droop controlled units (if any are available) in the microgrid

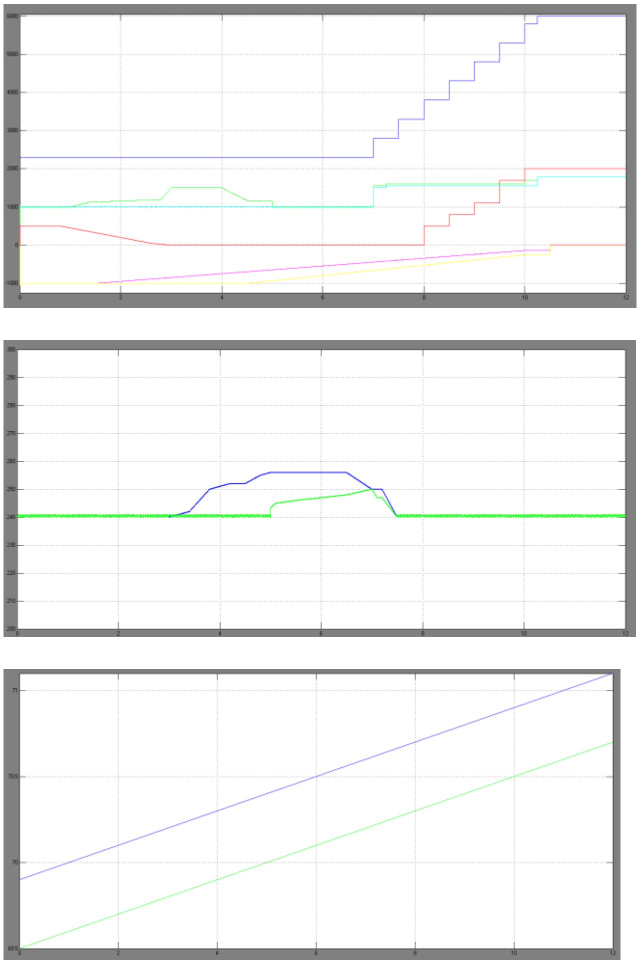
BLOCK DIAGRAM



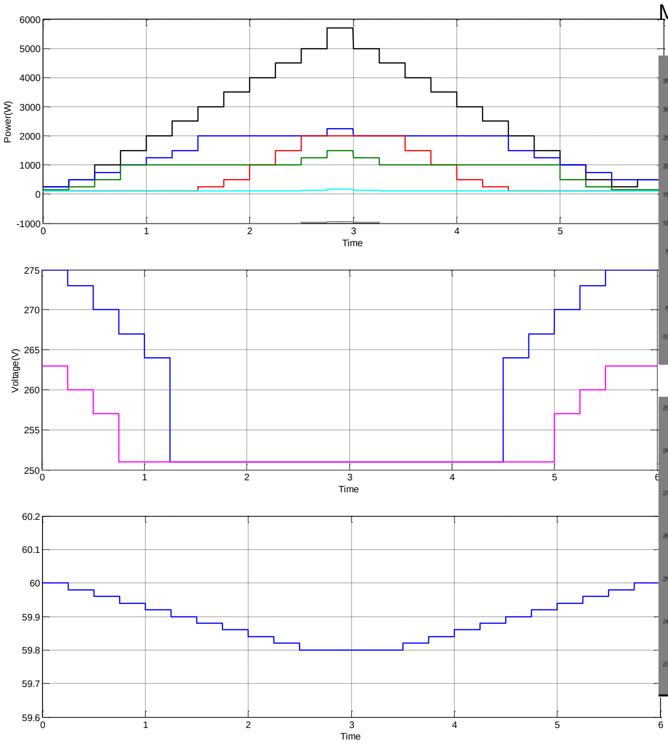
VI. SIMULATION RESULTS

SIMULATION RESULTS

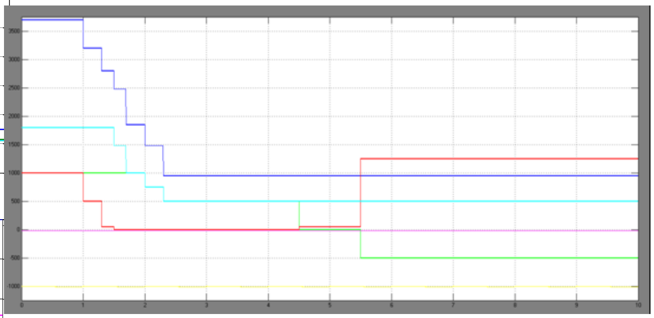
SCREEN SHOTS

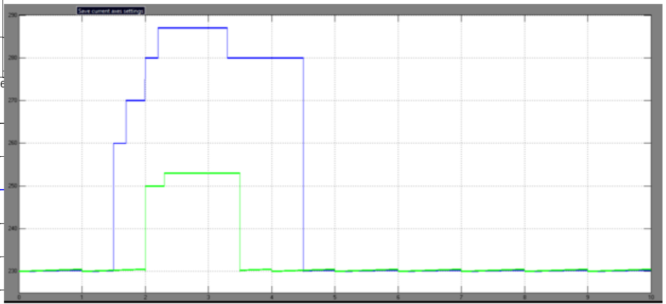


Microgrid response to variations in the SOC and the load.

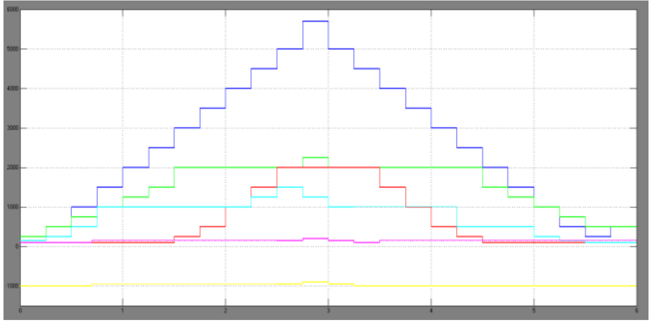


Performance of the microgrid in response to variations in the load





Microgrid response to solar irradiance and temperature variations



VII. CONCLUSION

It is demonstrated in this paper that decentralized power management of PV/battery hybrid units can be achieved using local voltage controllers that follow the proposed adaptive P=f characteristic curves. These curves are adjusted locally at each unit in real-time to adapt to various microgrid operating conditions. It is shown that the developed strategy can Autonomously maintain the power balance in the islanded microgrid, while ensuring a coordinated operation of the batteries in the hybrid units, without relying on any communications among different units.

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