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Theme: A Rule-based Energy Management of Solar-PV and Battery supplying Dc Load

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Abstract—The paper presents an energy management controller (EMC) using the Rules based strategy (RBS). The system consists of a photovoltaic array with 4.6kw as the main source and an energy storage system composed of load-acid battery that supplies a standalone DC load. Also The power of every source (PV module, battery) is modulated via a proper side static converters. And The different components of the system are simulated under Matlab/Simulink environment. Thus the obtained results prove the feasibility of the proposed approach, where the system switches smoothly between the operating modes.

Keywords: Hybrid system, energy storage, PV generator, Energy management system (EMS), indirect method control

1. Introduction:

Renewable energy sources (solar, wind, fuel cell, etc.) are considered as alternative energy sources to conventional fossil fuel energy sources due to the environmental pollution and global warming problems.Thecombination of all different kinds of available renewable energy associated with available energy storage units produces anhybrid energy system (HES). The utilization of the Hybrid systems requires a comprehensive energy management strategy to control the power flow among the elements consisting the hybrid electric system (HES). The EMS makes decision to generate and dispatch of electric power based on load profiles, weather conditions. Several authors have proposed different control strategies have been described for energy management system, these hybridizations may be contained a PV panel,wind, batteries, supercapacitors and even fuel cell.

Energy management of multi-power sources has already been studied recently, for example, Control, robustness, stability, efficiency, and optimization of hybrid sources remain an essential area of research. the authors in[1]proposean energy management of multi-power sources (pv-battery -supercapacitor). Therefore the EMC has been simply designed and developed using Stateflow approachIn [2]. HRES system energy management is done by using PI controller in[3]. In [4] a current control strategy for power balance is presented by PI controller. In addition, other studies proposed a maximum power point tracking (MPPT) controller using adaptive fuzzy logic approach combined with an energy management supervisor in order to ensure system efficiency under variation of operating conditions[5].

This paper focuses on design of control strategy for Hybrid Photovoltaic – Battery Generator supplies a standalone DC load. The PV system as a main source comprises several PV panels connected to the dc bus via a DC_DC buck-boost converter and storage devices (battery) are connected to a DC bus through a DC_DC bidirectional converter and a DC load shown Fig. 1. This paper is organized by the following sections: In section I, an explicit models of the different sub-systems are described, in section II, a control strategy of hybrid system. In section III, the simulation results are discussed. Finally, in section IV, the main conclusions are summarized.

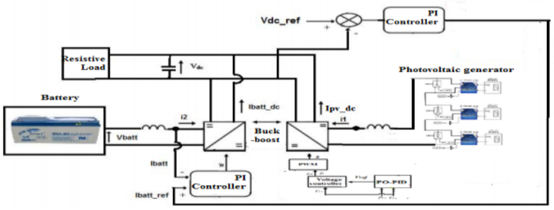

Fig1: System architecture

2.System Modeling:

A. PV Array Model

The equivalent circuit of the one-diode model is shown in Figure (2). The current source simulates the photo-current (Ipv) which depends on the irradiance and temperature. The ideal diode describes the cell polarization phenomena. The series resistance (Rs) is included to represent the internal cell resistance in the circuit. The shunt resistor (Rsh) is included to represent losses due to the diode leakage current. The output current of the one-diode model is described by.

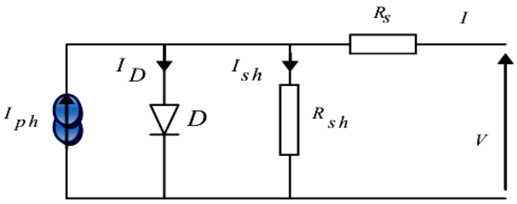

Fig 2: equivalent circuit of Photovoltaic module

Since Rsh is very high, The mathematical model for the current-voltage characteristic of a PV cell is given by [6]:

$$\mathrm{I} = \mathrm{I_{PV}}\text{-}\mathrm{I_0}\left[\exp\left(\frac{(\mathrm{V+R_S I_{pv}})}{\alpha \mathrm{V_T}}\right)\text{-}1\right]\text{-}[\frac{\mathrm{V+IR_S}}{\mathrm{R_p}}] \quad (1)$$

where$V_T = kT/q$ is the thermal potential, the diode current (I_D) is:

$$I_D = I_0\left[exp\left(\frac{V+R_S I_{pv}}{\alpha V_T}\right) - 1\right] \quad (2)$$

The output current of the solar cell Ipv, is the difference between the photocurrent Iph and reverse saturation current of the diode I_0. Rsrepresents the resistance of each cell and the shunt resistance Rsh has been neglected.

B. Battery model:

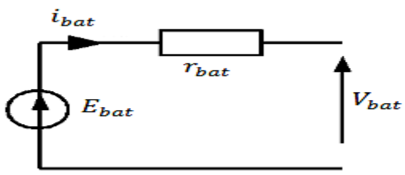

fig 3: Dynamic model of lead-acid battery

The battery voltage (V_{bat}) is given by:

$$V_{bat} = E_{bat} - R_{bat}.I_{bat} \quad (3)$$

I_{batt}, R_{batt} and E are the battery current, internal resistance and voltage[7] [8].

$$E = E_0 - K.\frac{Q}{Q-\int Idt} + Aexp(-B\int Idt \quad (4)$$

Here, Eo, K and Q are the battery constant voltage, the polarization voltage and the battery capacity. ∫Idt defines the actual battery charge by taking I as current. A is the exponential zone amplitude and B is the exponential zone time constant inverse. The SOC of the battery is presented in equation

$$SOC(t) = 100(1 - \frac{\int Idt}{Q}) \quad (5)$$

To increase battery life, state of charge of a battery must be maintained with in allowable limits. The SOC minimum and maximum limits of the Lead-acid battery are taken at 20 and 95%

C. models of the static converters:

1) DC/DC buck-boost converter model:

dc-dc converters play the role of adaptation stage between the PV module and the DC link

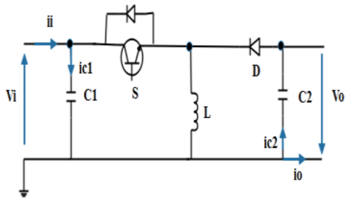

fig4:Schematic of buck-boost converter

The DC/ DC buck-boost converter is used due to its ability to track the MPP regardless of load variations and weather conditions ,the average model of the converter can be written as:

$$\begin{cases} c1\frac{dV_i(t)}{dt} = i_i(t) - \alpha i_L(t) \\ c2\frac{dV_o(t)}{dt} = (1-\alpha)i_L(t) - i_o(t) \\ L\frac{di_L(t)}{dt} = \alpha V_i(t) - (1-\alpha)V_o(t) \end{cases} \quad (6)$$

In order to maximize the energy extracted from the PV array, the indirect control, also known as the voltage based MPPT. this latter generates a reference voltage (V_{ref}); then a voltage controller is designed to adjust D so that the converter input voltage (V_{pv}). Figure 5

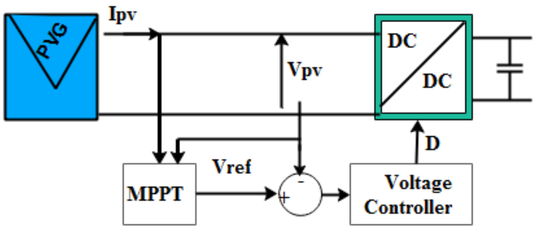

Fig 5: indirect structure control

P&O computes the reference voltage (Vref) and the voltage controller adjusts D to ensure PV output voltage matches V_{ref}. The change in power (ΔP) and voltage (ΔV) at each perturbation is calculated as follows:

$$\Delta P = P_{act} - P_{pre} \quad (7)$$

$$\Delta V = V_{act} - V_{pre} \quad (8)$$

Pact and V_{act} are the actual measured output power and voltage of PV, respectively. also, Ppre and Vpre denote the previous value for power and voltage[11]

$$V_{ref} = V_{ref} + \varphi_v sign(\Delta P.\Delta V) \quad (9)$$

2) Bidirectional DC/DC converter model

The bidirectional DC/DC converter is a current reversible DC/DC converter. It can work as a boost converter when the current (of the bidirectional DC/DC converter inductance) flows from the battery to the DC bus. It works as buck converter when the current flows on the opposite direction [10]. Thus, to achieve energy transfer in two directions, the buck and boost converters were associated.

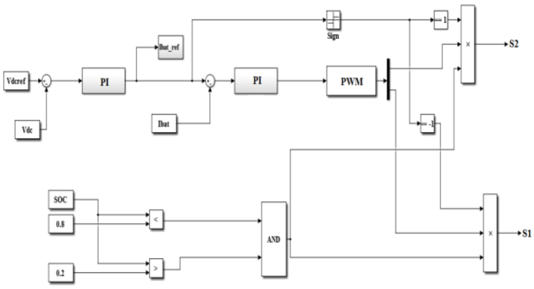

fig6.bidirectional converter control

3.The Operation Modes of energy management

In the present work, three operating modes are distinguished and smoothly permuted through the presented power management system. Throughout the simulation the photovoltaic generator operates on MPPT:

- **Mode1:** the PV array and the battery, supply the load.

- **Mode2:** power load is below to the maximum power point (MPPT), then the battery is charged.

- Mode3: This mode starts when the power of the PV array demand equal to the power demand, where the Photovoltaic array supplies only the load demand.

To permit a global flow of the different source's energy, the DC bus must be kept constant in the EMS depicted in (Fig 6).

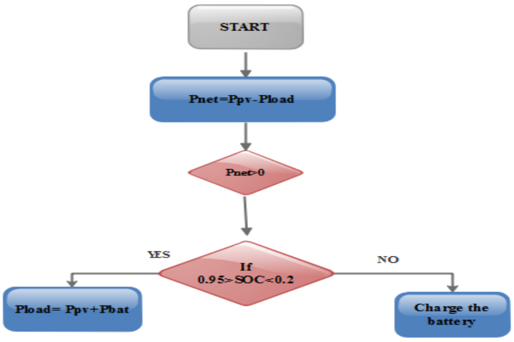

Fig 7: Energy management system

A. battery current control loop

The design of the bidirectional DC-DC converter of the battery is based on PI. The controller PI delivers the reference battery current (Ibat_ref).The latter will be compared with abattery current (Ibat).Finally the error of this comparison is sent to a PWM for generating the duty cycle (D) of the bidirectional converter to operate the converter in boost or buck mode [10].

B. PV current control loop

The PV panels are equipped with the maximum power point tracking controller to track the MPP and extract maximum possible power from the panel[14].

In this study, Proposition of Sliding Mode Controller: Integrating a robust voltage controller can improve the overall performance of the MPPT. The average model of the Buck-boost shown in (4) is used for developing the controller. It can be rewritten as follows

$$\begin{cases} \dot{x}_1 = \frac{i_i(t)}{c_1} - \frac{x_3}{c_1}u \\ \dot{x}_2 = \frac{x_3}{c_2} - \frac{i_0(t)}{c_2} - \frac{x_3}{c_2}u \\ \dot{x}_3 = -\frac{x_2}{L} + \frac{x_1}{L}u - \frac{x_2}{L}u \end{cases} \quad (11)$$

where system states x1, x2 and x3 are $V_i(t)$, $v_o(t)$ and iL(t), respectively.

The objective is to develop a control law for α, denoted by u(t), to annul the tracking error e(t), which is defined by[11]:

$$e(t) = x_1 - x_{1ref} \quad (12)$$

$$u(t) = \frac{i_i(t)}{x_3} + \frac{c_1}{x_3}ksgn\big(S(t)\big) \quad (13)$$

the expression of the duty cycle α is therefore obtained as follows:

$$\alpha = \frac{i_i(t)}{x_3} + \frac{c_1}{x_3}ksgn\left(V_i(t) - V_{iref}(t)\right) \quad (14)$$

4.Simulation Results and Discussion:

Fig 8 shows The load demand, the extracted PV generated power and the battery power over the overall time span.

- During the first interval [0s and 7s] the net power Pnet is negative, and the system operates in mode 1. the PV power does not cover the load demand. As a result the battery is discharged.
- During the second interval [7s and 12s]the net power Pnet is positive, the PV generator satisfies the load demand and , the system operates in mode 2 the excess of power is used to charge the battery.
- During the third interval [12s and 15s] the net power Pnet takes zero values the PV supplies only the load demand.

In Fig 11, state of charge increase and decrease correspond to a charge or discharge.

As can be seen, the PI controller success to maintain this voltage constantly at a rated value (700v) (fig 12) with certain overshoot during the variation of the load and tracks its reference perfectly, under a settling time of (0.02s).

Fig 13 presents the Robustness of the MPPT P§O based on indirect control.

Fig 14 shows the battery current. It tracks well the reference, this current becomes positive to compensate for an increase in the load power demand that oppears between (t= 0s and t=4s) resulting the discharge of the battery, negative when the battery is charged (for example between t=12s and t=15s) and takes zero values if the battery is completely Charged.

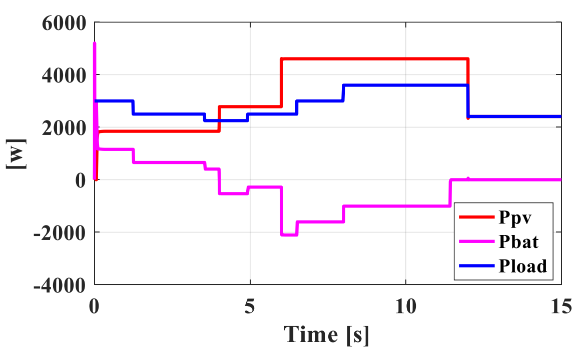

Fig 8 : Load and PV and battery Power

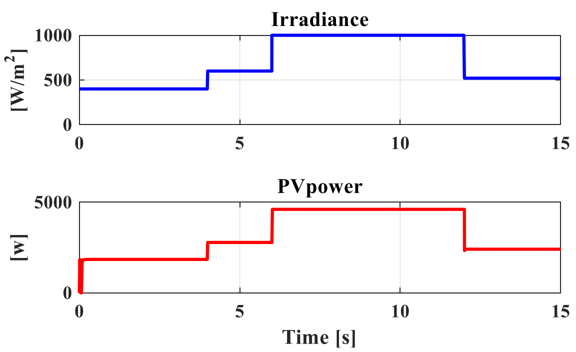

Fig 9: Irradiance vs. Power

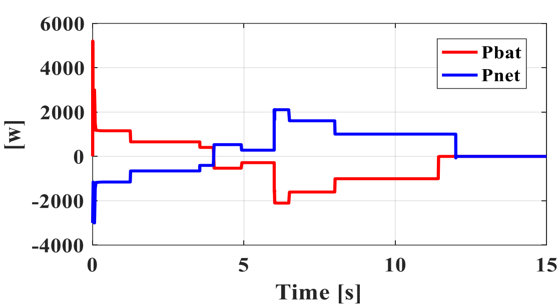

Fig 10 : Pbat.vs.Pnet

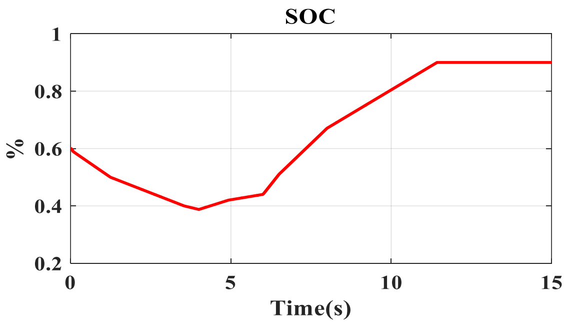

Fig 11 : State of charge

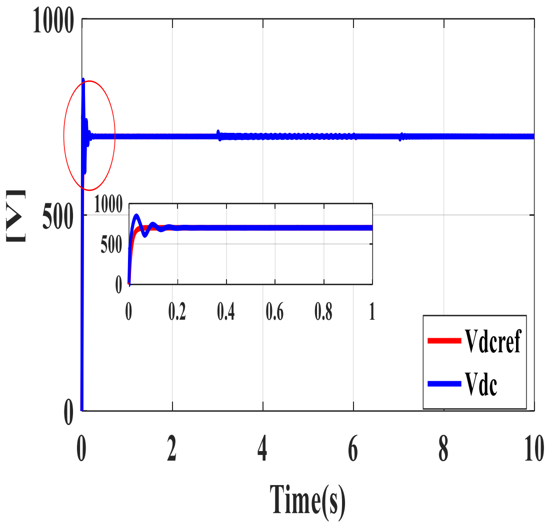

Fig 12: dc-link voltage

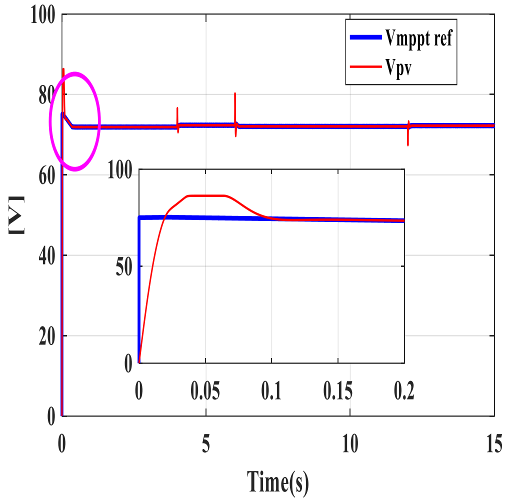

Fig 13: BuckBoost converters controls

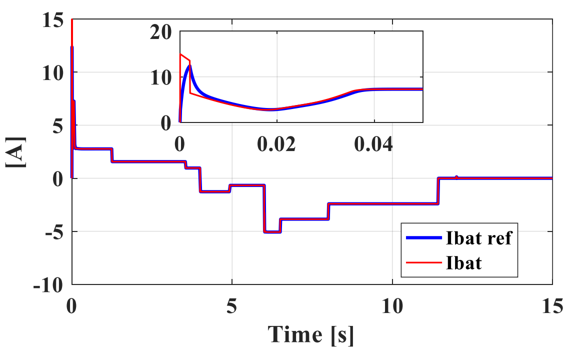

Fig 14: refrences currents battery

5.Conclusion

This paper presents an energy management of hybrid system consisting of PV, battery for dc load.Modelingof the studied energy system has been carried out using Matlab/Simulink environment.The battery stores power generated by the PV enable to continue the operation in maximum power point during high load demand. Simulation results performed and validate the effectiveness of the proposed control system

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