

Ripple correlation MPPT and Robust Controller for Grid-Connected Photovoltaic Systems

Hassan Abouobaida Mohamed Cherkaoui

Department of Electrical Engineering, Ecole Mohammadia d'ingénieur, Mohamed V University,
Rabat, Morocco

Email: Hassan_abouobaida@yahoo.fr , Cherkaoui@emi.ac.ma

Abstract—The present work describes the analysis, modeling and control of a Boost-Buck power inverter used as a DC-DC and DC-AC power conditioning stage for grid-connected photovoltaic (PV) systems.

To maximize the steady-state input-output energy transfer ratio a backstepping controller is designed to assure output unity power factor and a Maximum Power Point Tracking (MPPT) algorithm to optimize the PV energy extraction. The achievement of the DC-AC conversion at unity power factor and the efficient PV's energy extraction are validated with simulation results.

Keywords: MPPT, unity power factor, backstepping controller, Lyapunov

1. Introduction

Many renewable energy technologies today are well developed, reliable, and cost competitive with the conventional fuel generators. The cost of renewable energy technologies is on a falling trend as demand and production increases. There are many renewable energy sources such as solar, biomass, wind, and tidal power. The solar energy has several advantages for instance clean, unlimited, and its potential to provide sustainable electricity in area not served by the conventional power grid.

However, the solar energy produces the dc power, and hence power electronics and control equipment are required to convert dc to ac power. There are two types of the solar energy system; stand-alone power system and grid-connected power system. Both systems have several similarities, but are different in terms of control functions. The stand-alone system is used in off-grid application with battery storage. Its control algorithm must have an ability of bidirectional operation, which is battery charging and inverting. The grid-connected system, on the other hand, inverts dc to ac and transfers electrical energy directly to power grid. Its control function must follow the voltage and frequency of the utility-generated power presented on the distribution line. With a GCI (grid

connected inverter) excess power is bought and credited by the utility, and grid power is available at times when the local demand exceeds the PV system output [1].

Usually, the power stage circuits in charge of performing the dc-ac conversion are based on a full-bridge buck switching converter topology [1]-[2]. Regarding the control subsystem, several control schemes oriented to ensure a proper tracking of an external sinusoidal reference have been suggested. For instance, many tracking control techniques based on high-frequency pulse width modulation (PWM) have been proposed in the past for buck based dc-ac converters.

On the other hand, backstepping mode control techniques have been proposed as an alternative to PWM control strategies in dc-ac switching regulators since they make these systems highly robust to perturbations, namely variations of the input voltage.

A power conditioning system linking the solar array and the utility grid is needed to facilitate an efficient energy transfer between them; this implies that the power stage has to be able to extract the maximum amount of energy from the PV and to assure that the output current presents both low harmonic distortion and robustness in front of system's perturbations [3].

In order to extract the maximum amount of energy the PV system must be capable of tracking the solar array's maximum power point (MPP) that varies with the solar radiation value and temperature. Several MPPT algorithms have been proposed, namely, Perturbation and Observation (P&O), incremental conductance, fuzzy based algorithms, etc. They differ from its complexity and tracking accuracy but they all required sensing the PV current and/or the PV voltage [4].

Several controller strategies have been used in the literature, citing the PI in [5] that is generally suitable for linear systems, the sliding mode in [6] for which the chattering problem, and fuzzy logic proposed

adjustment in adapted to systems without a mathematical model [7].

In this paper, a backstepping control strategy is developed to maximize the power of a solar generating system and to assure that the output current presents both low harmonic distortion and robustness in front of system's perturbations. The desired array voltage is designed online using a RCC (Ripple Correlation Control) MPP tracking algorithm [8]. The proposed strategy ensures that the MPP is determined and the system errors are globally asymptotically stable. The stability of the control algorithm is verified by Lyapunov analysis [9].

The rest of the paper is organized as follows. The dynamic model of the global system (GPV, buck inverter (PWM)) is described in Section II. A backstepping controller is designed along with the corresponding closed-loop error system and the stability analysis is discussed in Section III. In Section IV, a simulation results proves the robustness of the controller with respect solar radiation and temperature change.

2. MPPT System Modeling

The solar generation model consists of a PV array module, dc-to-dc boost converter and a dc-to-ac buck inverter as shown in Fig1.

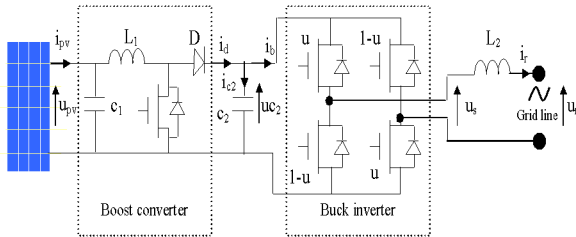


Fig. 1. Cascade connection of a boost converter with a full-bridge buck inverter

II.1 PV model

PV array is a p-n junction semiconductor, which converts light into electricity. When the incoming solar energy exceeds the band-gap energy of the module, photons are absorbed by materials to generate electricity. The equivalent-circuit model of PV is shown in Fig2. In this model, it consists of a light-generated source, diode, series and parallel

resistances. Where R_s is relatively small and R_p is relatively large, which are neglected in the equation in order to simplify the simulation [10]-[11].

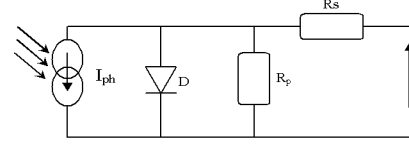


Fig : 2 : equivalent model of solar cell

II.2 inverter model

The active power transfer from the PV panels is accomplished by power factor correction (line current in phase with grid voltage). The inverter operates as a current-control inverter (CCI). Noticing that u stand for the control signal of buck inverter, the system can be represented by differential equations (1) [3].

$$C_2 \cdot \dot{u}_{c2} = i_d - i_b \quad (1)$$

$$L_2 \cdot \dot{i}_r = u_s - u_r$$

$$u_s = (2 \cdot u - 1) \cdot u_{c2}$$

$$i_r = (2 \cdot u - 1) \cdot i_b$$

Where $u \in [0,1]$

Where u_{c2} , u_s , u_r designs a DC voltage, output inverter voltage and AC grid voltage, respectively. And i_d , i_b , i_r are converter output current, inverter input current and grid current, respectively.

Using the state averaging method (on cutting period), the switched model can be redefined by the average PWM model as follows:

$$C_2 \cdot \dot{u}_{c2} = i_d - u_{c2} \frac{i_r}{u_s} \quad (2)$$

$$L_2 \cdot \dot{i}_r = \beta \cdot u_{c2} - u_r \quad (3)$$

Where β is averaging value of $(2 \cdot u - 1)$

3. Control design

The backstepping approach is a recursive design methodology. It involves a systematic construction of both feedback control laws and associated Lyapunov functions. The controller design is completed in a number of steps, which is never higher than the system order.

Two main objectives have to be fulfilled in order to transfer efficiently the photovoltaic generated energy

Step 2. Let us investigate the behavior of error variable e_2 .

In view of (1) , time-derivation of e_2 turns out to be:

$$\dot{e}_2 = i_r - i_r^* = \frac{\beta \cdot u_{c2} - u_r}{L_2} - i_r^* \quad (11)$$

From (7) one gets:

$$\dot{q}_1 = \dot{i}_r^* = \frac{(k_1 \cdot c_2 \cdot e_1 + i_d) \cdot (\dot{u}_r \cdot u_{c2} - u_r \cdot \dot{u}_{c2}) + u_r \cdot u_{c2} \cdot (k_1 \cdot c_2 \cdot \dot{e}_1 + \dot{i}_d)}{(u_{c2})^2} \quad (12)$$

which together with (11) implies:

$$\dot{e}_2 = \frac{\beta u_{c2} - u_r}{L_2} - \frac{(k_1 \cdot c_2 \cdot e_1 + i_d) \cdot (\dot{u}_r \cdot u_{c2} - u_r \cdot \dot{u}_{c2}) + u_r \cdot u_{c2} \cdot (k_1 \cdot c_2 \cdot \dot{e}_1 + \dot{i}_d)}{(u_{c2})^2} \quad (13)$$

In the new coordinates (e_1, e_2) , the controlled system is expressed by the couple of equations (10) and (13). We now need to select a Lyapunov function for such a system. As the objective is to drive its states (e_1, e_2) to zero, it is natural to choose the following function:

$$V = \frac{1}{2} \cdot e_1^2 + \frac{1}{2} \cdot e_2^2 \quad (14)$$

The time-derivative of the latter, along the (z_1, z_2) trajectory, is: (substituting (2)-(3) in (13) and using (12))

$$\dot{V} = e_1 \cdot \dot{e}_1 + e_2 \cdot \dot{e}_2 = -k_1 \cdot e_1^2 - k_2 \cdot e_2^2 + e_2 \cdot \left[\frac{\beta u_{c2} - u_r}{L_2} - i_r^* + k_2 \cdot e_2 \right] \quad (15)$$

where $k_2 > 0$ is a design parameter and i_r^* is to be replaced by the right side of (12). Equation (15) shows that the equilibrium $(e_1, e_2) = (0, 0)$ is globally asymptotically stable if the term between brackets in (15) is set to zero. So doing, one gets the following control law:

$$\beta = \frac{[-k_2 \cdot e_2 \cdot L_2 + u_r]}{u_{c2}} + \frac{L_2 \cdot [(k_1 \cdot c_2 \cdot e_1 + i_d) \cdot (\dot{u}_r \cdot u_{c2} - u_r \cdot \dot{u}_{c2}) + u_r \cdot u_{c2} \cdot (k_1 \cdot c_2 \cdot \dot{e}_1 + \dot{i}_d)]}{(u_{c2})^3} \quad (16)$$

Proposition : Consider the control system consisting of the average PWM Buck model in closed-loop with the controller (12), where the desired DC voltage reference u_{c2}^* is sufficiently smooth. Then, the equilibrium $i_r \rightarrow i_r^*$, $u_{c2} \rightarrow u_{c2}^*$ and $\beta \rightarrow \mu$ is locally asymptotically stable where :

$$\mu = L_2 \cdot \frac{[i_d \cdot (\dot{u}_r \cdot u_{c2} - u_r \cdot \dot{u}_{c2}) + u_r \cdot u_{c2} \cdot \dot{i}_d]}{(u_{c2})^3} + \frac{u_r}{u_{c2}} \quad (17)$$

II. Simulation result :

The PV model, boost-buck inverter model, and proposed MPPT approach are implemented in Matlab/Simulink as illustrated in Figure 3. In the study, RSM-60 PV module has been selected as PV power source, and the parameter of the components are chosen to deliver maximum 1kW of power generated by connecting 16 module of RSM-60 in parallel. The specification of the system and PV module are respectively summarized in the following table.

Control parameters used in the simulation		
parameters	Value	unit
k_1	100	
k_2	1130	
Characteristics of the photovoltaic generator		
Maximum power	P_{pv_max}	60 w
Output voltage at P_{max}	u_{pv_max}	16v
Open-circuit voltage	Voc	21.5v

A Matlab® simulation of the complete system with the backsteeping controller and the RCC MPPT has been carried out using the following parameters:

- $L_1=1\text{mH}$, $L_2=2\text{mH}$, $c_1=220\mu\text{F}$, $c_2=2\text{mF}$
- Buck switching frequency = 25kHz
- RCC MPPT frequency = 100kHz

The proposed controller is evaluated from tow aspects : robustness to irradiance and temperature . In each figures, two different values of irradiance and temperature are introduced in order to show the robustness. Figure 4 shows the simulation results of the designed inverter when the solar radiation changes from 500W/m^2 to 1000W/m^2 and then the temperature

change from 25°C to 30°C at $t=2s$ and $t=2.5s$ respectively. Notice that according to figure 4.c the maximum power point is always reached after a smooth transient response and that the power of photovoltaic generator (GPV) reaches the commanded value according to radiation change and temperature and that the DC-link capacitor voltage reaches the commanded value of 450V which is greater than AC grid voltage.

From figure 5.a , it can be seen that the output current is in phase with the utility grid voltage.

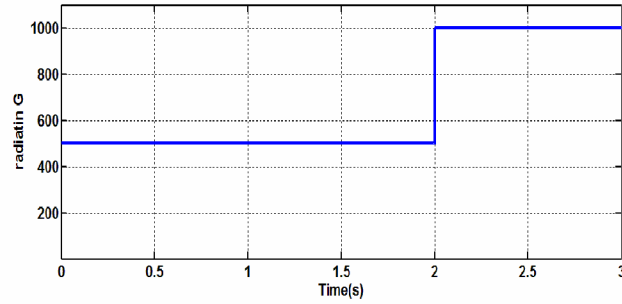


Fig 4.a

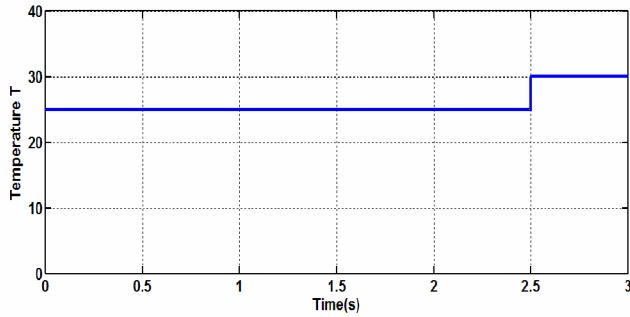


Fig 4.b

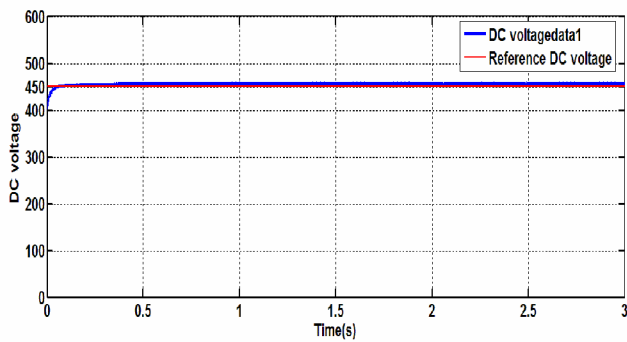


Fig 4.c

Fig. 4. Simulation results. (a) radiation , (b) temperature , (c) DC voltage

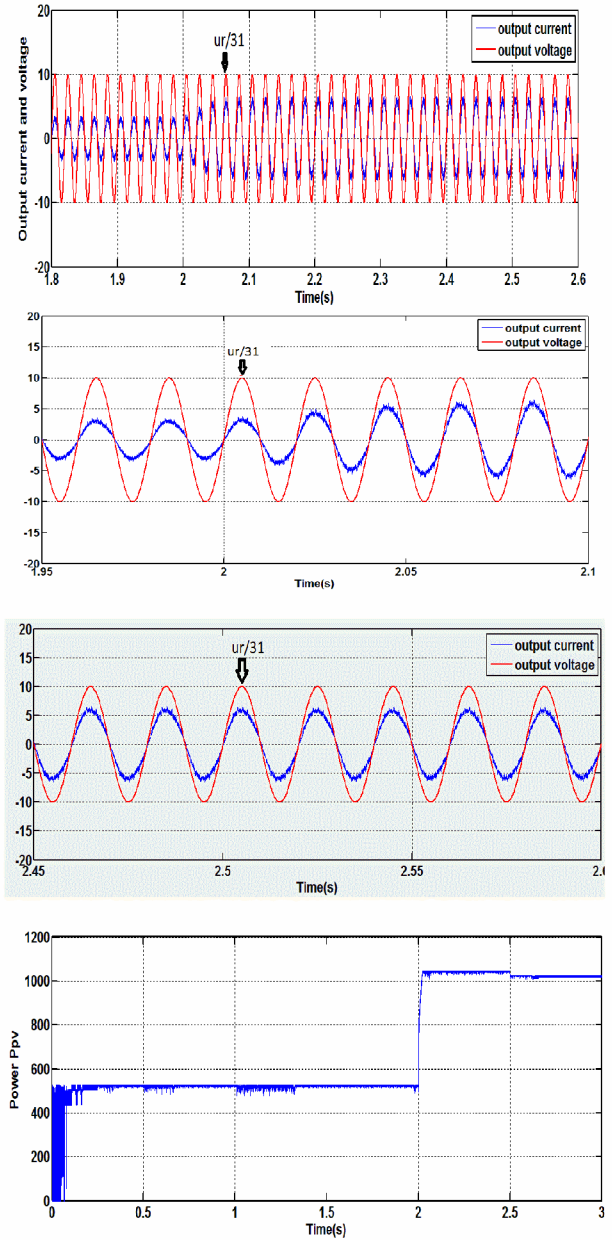


Fig. 5. Simulation results. Output voltage and current, GPV power

V. Conclusions

A backstepping control strategy has been developed for a solar generating system to inject the power extracted from a photovoltaic array and obtain unitary power factor in varying weather conditions. A desired array voltage is designed online using an MPPT searching algorithm to seek the unknown optimal array voltage. To track the designed trajectory, a tracking controller is developed to modulate the duty cycle of the boost-buck inverter. The

proposed controller is proven to yield global asymptotic stability with respect to the tracking errors via Lyapunov analysis. Simulation results are provided to verify the effectiveness of this approach .

References :

- [1] G. Ertasgin, D.M. Whaley, N. Ertugrul and W.L. Soong , A Current-Source Grid-Connected Converter Topology for Photovoltaic Systems , Australasian Universities Power Engineering Conference. AUPEC'06. 2006 : Melbourne, Australia.
- [2] Fritz Schimpf ,Lars E. Norum ,Grid connected Converters for Photovoltaic, State of the Art, Ideas for Improvement of Transformerless Inverters , NORPIE/2008, Nordic Workshop on Power and Industrial Electronics, June 9-11, 2008
- [3] Carlos Meza , Domingo Biel , Juan Negroni, Francesc Guinjoan , Boost-Buck Inverter Variable Structure Control for Grid-Connected Photovoltaic Systems with Sensorless MPPT , IEEE ISIE 2005, June 20-23, 2005, Dubrovnik, Croatia
- [4] : Trishan Eram., Patrick L. Chapman, Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques , IEEE Transaction on Energie Conversion, VOL. 22, NO. 2, JUNE 2007 ,pp 439 - 449
- [5] T. Ostrem, W. Sulkowski, L. E. Norum, and C. Wang , Grid Connected Photovoltaic (PV) Inverter with Robust Phase-Locked Loop (PLL) , 2006 IEEE PES Transmission and Distribution Conference and Exposition Latin America, 15-18 Aug. 2006 , Caracas ,Venezuela.
- [6] Domingo Biel, Member, IEEE, Francesc Guinjoan, Enric Fossas, Javier Chavarria , Sliding-Mode Control Design of a Boost-Buck Switching Converter for AC Signal Generation , IEEE Transaction On Circuit And System I , vol. 51, NO. 8, AUGUST 2004, pp 1539 – 1551.
- [7] Nopporn Patcharaprakiti, Suttichai Premrudeepreechacharn, Yosana Sriuthaisiriwong ,Maximum power point tracking using adaptive fuzzy logic control for grid-connected photovoltaic system ,Renewable Energy, Volume 30, Issue 11, September 2005, pp 1771-1788 .
- [8] Jonathan W. Kimball , Philip T. Krein Digital Ripple Correlation Control for Photovoltaic Applications , Power Electronics Specialists Conference IEEE , Orlando, FL , June 2007, pp. 1690 – 1694
- [9] Khalil, H. K., 1996, Nonlinear Systems, 2nd ed.,Prentice Hall, New York, USA.
- [10] Marcelo Gradella Villalva, Jonas Rafael Gazoli, and Ernesto Ruppert Filho , Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays , IEEE Transaction On Power Electronics, vol. 24, NO. 5, May 2009, pp : 1198 – 1208
- [11] Campbell, R.C. A Circuit-based Photovoltaic Array Model for Power System Studies , Power Symposium , NAPS '07. 39th North American, December 2007 , pp : 97 – 101