3rd International Conference on Green Energy and Environmental Engineering (GEEE-2016)
Proceedings of Engineering & Technology (PET)
pp. 61-67

An optimized stand-alone photovoltaic system in south Mediterranean countries

Hanen Nafaa#1, Maissa Farhat*2, Sbita Lassaad#3
[#] *University of Gabes,*
Research Unit of Photovoltaic, Wind and Geothermal systems,
[1] hanen_nafaa@yahoo.fr
[2] maissa.farhat@gmail.com
[3] lassaad.sbita@enig.rnu.tn

National Engineering school of Gabes, Street of Mednine 6029 Gabes, Tunisia.

***Abstract*— this paper describes the design and implementation of virtual stand-alone photovoltaic power systems. In this work a development work was done in order to predict the photovoltaic (PV) generator behaviors under prevailing meteorological conditions in south Mediterranean countries; the solar flux that is consider as input for the PV generator is imported from Meteo database. An Alternative load with a maximum power tracker (MPPT) was implemented in order to optimize the system efficiency. The interface between the solar panel and the load was carried out using photovoltaic inverter, charge controller and battery.**

***Keywords*— maximum-power-point-tracking; photovoltaic energy; conversion system; solar generator; battery.**

I. INTRODUCTION

Since the introduction of the industrial era, mankind continues increasing energy consumption in many forms meet the complexity of companies (industry, transport, heating, electricity, etc ...) [1].

This development could only thanks about the massive use of fossil fuels.

Now and in the coming years, consumers and taxpayers, policy makers and regulators, stakeholders and advocates, investors and planners, as well as visionaries and builders make decisions that will determine the future of the electricity infrastructure for future generations. Will talk about how people might come understand the value of electricity and the choices that will ensure that electricity continues to be approachable, reliable and sustainable.

So it is a challenge to make available the rural population as a source of energy capable of stimulating economic activity and lead to an improvement in their living conditions. Photovoltaic (PV) energy is the most important energy resource since it is clean, pollution free, and inexhaustible [2]. Due to rapid growth in the semiconductor and power electronics techniques, Off grid electric systems based on renewable energy sources present a huge commitment for these areas. Solar photovoltaic (PV) systems convert solar energy directly into electricity and offer the advantage of long lifetime with minimal maintenance. However, unlike most mature technologies, its costs are continuing to decline and solar PV is increasingly commercially attractive to project developers and to small-scale residential or commercial consumers. TUNISIE (in south Mediterranean countries) has high solar irradiation level. The annual daily average solar irradiation on a horizontal surface ranges between 2.9 and 8.07 kWh/m2 [3].

This paper therefore aims at stressing the applicability of solar PV technology in south Mediterranean countries through a design and implementation of Virtual Stand-Alone Photovoltaic (VSAP) power systems [4]. PV energy is of increasing interest in electrical power applications. It is important to operate PV energy conversion systems near the maximum power point to increase the output efficiency of PV arrays. In general a PV system is typically built around the following main components as shown in figure 1:

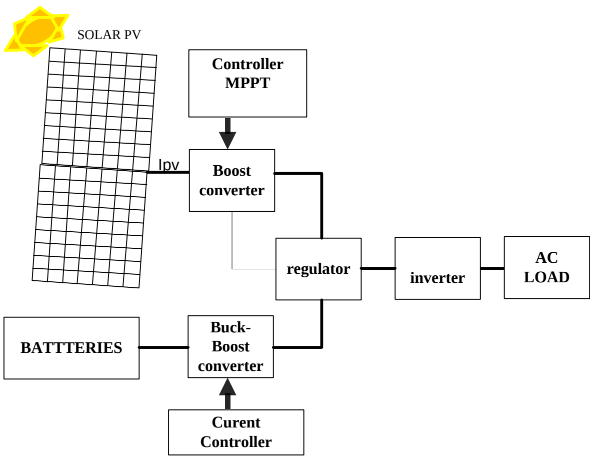


Fig. 1. The PV system model.

ISSN: 2356-5608

The VSAP system model employed in this analysis is portrayed in this section. Fig. 1 illustrates the proposed system configuration, composed the PV generator, the MPPT, boost converter, the bidirectional converter with battery and the inverter.
The PV array functions to convert sun radiation into DC power. For this study, meteorological data was imported from Meteo database. The battery stores excess energy and the inverter converts DC power into AC power to match AC appliances.

II. SOLAR CELL/ARRAY MODELING:

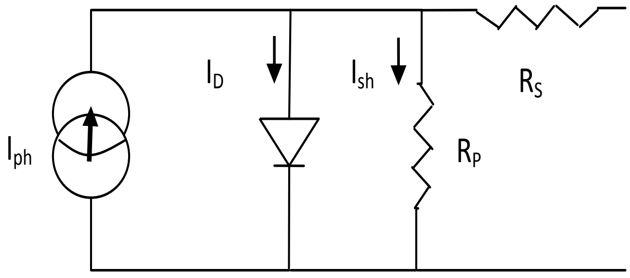


Fig. 2. the solar PV panel model

The electrical equivalent-circuit of a solar cell is shown in Fig. 2(a). It is composed of a light-generated current source, diode, series resistance, and parallel resistance. The characteristic equation for the current and voltage of a solar cell is given as follows:

$$I = N_P I_{ph} - I_d - I_{sh} \quad (1)$$

The photocurrent of the module I_{ph}, can be calculated as:

$$I_{ph} = \lambda\left(I_{SC} + K_1\left(T - T_{REF}\right)\right) \quad (2)$$

With:

$$\lambda = \frac{G}{G_S}$$

The diode current is given by the Shockley's diode equation [5]:

$$I_d = I_{sat}\left(\exp\frac{\left(\frac{V + IR_S}{N_S}\right)q}{TKn_S} - 1\right) \quad (3)$$

The reverse saturation current I_{sat}, is dependent of temperature, and it is described in this equation:

$$I_{sat} = I_{RS}\left(\frac{T}{T_{REF}}\right)^3 EXP\left[\frac{qE_g\left(\frac{1}{T_{REF}} - \frac{1}{T}\right)}{KA}\right] \quad (4)$$

With
$$I_{RS} = \frac{I_{SC}}{\left[EXP\left(\frac{qV_{OC}}{n_S K T_C A}\right) - 1\right]} \quad (4)$$

With:
T : The junction temperature in Kelvin (K).
T_{REF} : The reference temperature of the PV cell in Kelvin, usually 25°C.
A: Diode ideality factor (1<A<2) is dependent on PV technology.
q: Electron charge.
K: Boltzmann constant.
V: voltage (V).
The photocurrent of the module I_{ph}, can be calculated as:

$$I_{ph} = \lambda\left(I_{SC} + K_1\left(T - T_{REF}\right)\right) \quad (5)$$

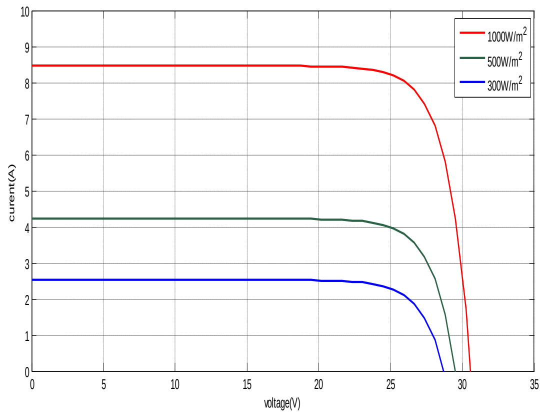
With:

$$\lambda = \frac{G}{G_S}$$

The Shunt current is given by:

$$I_{sh} = \frac{(V + IR_S)}{R_P} \quad (6)$$

With the aforementioned equations, a model simulate the PV panel in MATLAB/SIMULINK was created. Where the definition of PV model parameters are listed in Table I. Figure 3, illustrates the I-V and P-V characteristics of the PV panels used in this research at a solar temperature 25°C and irradiation 1000W/m^2, 500W/m^2, 300 W/m^2 ,if the PV panels are connected to resistive load .



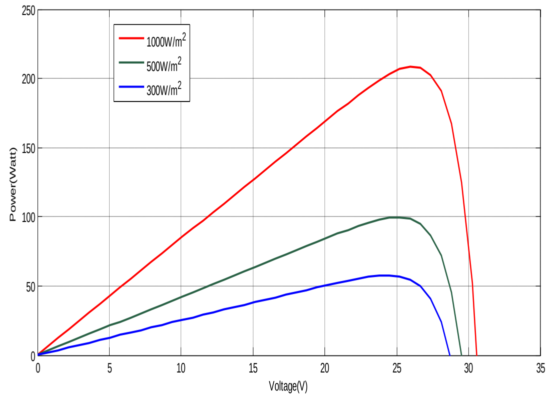


Fig. 3. (a) V-I and (b) P-V characteristic. For PV panel

III. Storage Battery:

A stand-alone solar PV system is usually coupled with energy storage devices to ensure reliable supply. The most commonly used energy storage device is a battery, mainly lead acid type. Lead-acid batteries are used almost exclusively in photovoltaic stand-alone systems. Although most other types of batteries have advantages such as high storage density or lower self-discharge, the decisive advantage of the lead battery is its lower price Batteries make up the largest component cost over the lifetime of a stand-alone solar PV system.

The solar battery leads to the following model for load and off-load [6] based on equation given in:

$$V = nE \pm nRI \tag{7}$$

With: E is the initial voltage; where the +sign is for the charge and – sign for the discharge.

The equivalent circuit of storage system can be represented as in figure4:

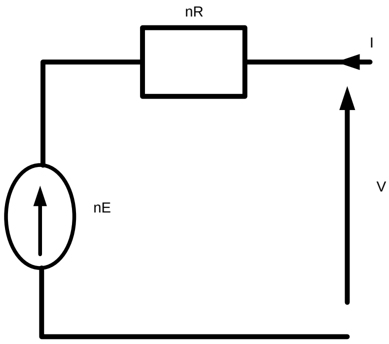


Fig. 4. Equivalent electrical diagram of battery system

IV. The DC-DC converter :

The DC-link inverter uses a boost converter to amplifying the voltage generated by the PV module or a battery charging controller (buck boost converter).

A. The Boost Converter :

The only task for the boost converter is to amplify the voltage level generated by the PV module. Besides this, it is sufficient to design the DC-DC converter for the maximum power.

A boost converter produced DC voltage by the PV arrays to a load voltage is typically built around the following main components as shown in figure 5.

The boost converter must be localized between the solar panel and DC-AC inverter. This converter can be controlled by a sliding mode control.

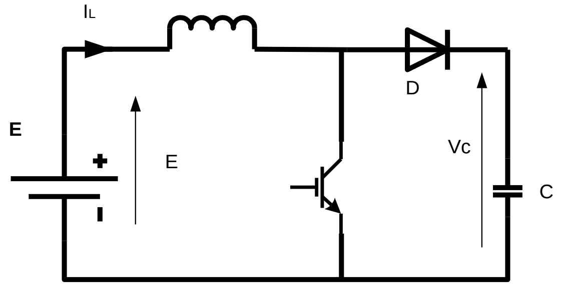


Fig. 5. Synoptic diagram of DC/DC boost converter

Boost converter is DC-DC converters [7] that step up its input voltage based on equation given in (8):

$$V_{out} = \frac{1}{1-D} v_{in} \tag{8}$$

Where V_{out} is the output voltage of the boost converter, V_{in} the input voltage.

B. The Buck Boost Converter :

The buck-boost converter is necessary to connect the battery stack to the power inverter system and it comes into operation when the electrical power demanded by consumers is higher than the electrical power obtained from the PV generator. Another reason for the use of the buck-boost converter is to recharge the batteries from the other available sources.

Buck-Boost converter is DC-DC converters [8] that step up its input voltage based on formula given in (9):

$$V_{bat} = \frac{D}{1-D} v_{in} \tag{9}$$

Where V_{bat} is the output one of the buck-boost converter and V_{in} the input voltage and D is the duty cycle.

The buck-boost converter is shown in Fig 4.

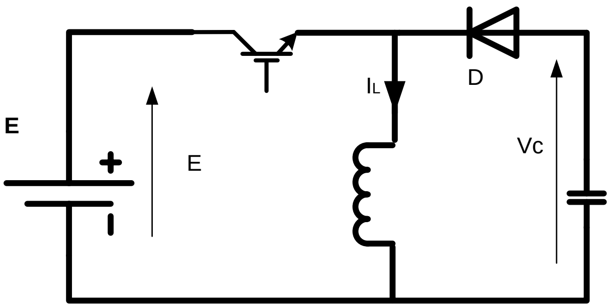


Fig. 6. Synoptic diagram of DC/DC buck- boost converter

The dynamic model of the Buck-Boost converter circuit is given by (10) [9]:

$$\begin{cases} \frac{dI_L}{dt} = D\frac{E}{L} + (1-D)\frac{v_c}{L} \\ \frac{dv_c}{dt} = -\frac{v_0}{RC} - (1-D)\frac{I_L}{c} \end{cases} \quad (10)$$

V. THE AC-DC CONVERTER AND CONTROLLER DESIGN :

A. The DC-AC converter:

A single phase voltage inverter is used to interface the DC-DC converter with the AC load (RLC) by converting the power. It permits the conversion from a DC to AC[10].

This paper focuses on the use of a fixed DC bus input voltage by the use of a multi source power.

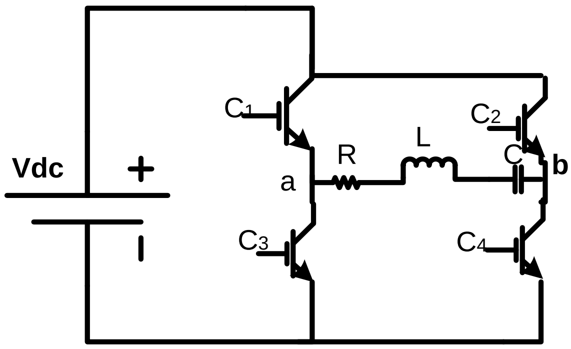


Fig. 7. Voltage Source Inventer topologie

The inverter provides a single phase voltage system which follows the tow reference voltages PWM commands. The output voltages feed the AC load.

These output voltages can be expressed as Indicated in equation (11):

$$v_{ab} = V_{DC}(c_1 - c_2) \quad (11)$$

With V_{DC} is the output voltage. c_1 and c_2 are the PWM gates control signals.

B. CONTROLLER DESIGN:

The aim of this section is developing the controllers used in this paper:

(i) Achieve the MPPT even with variations of irradiation and temperature PV array with sliding mode control.

(ii) The Current Controller.

(iii) Inject of two sources to inverter.

1) *MPPT Controller:*

In this study, The MPPT controller will be synthesized using SMC control [11].

The fundamental principle of an SMC is to design a particular sliding manifold in its control law that will preside over the trajectory of the state variables towards the required operating point.

After determined the Vref the implemented (SMC) algorithm calculate the difference between the acquired PV voltage and the Vref and then, via the boost converter force the PVG to operate at the reference voltage value (Vref) and therefore at the maximum power zone.

In case of a boost converter as it has a single switch, it is apt to adopt a control law for a switching function [12] as

$$u = \frac{1}{2}\left(1 + sign(S)\right) \quad (12)$$

The sliding mode surface S consists of the voltage error:

$$S = V_{ref} - V \quad (13)$$

It is guaranteed that the system state will hit the surface and produce maximum power output persistently.

When the present position of balance point is determined by the gradient detector; The Switching Element was used to determine whether the present signal should be changed, and then multiplied by integral gain to obtain a transaction of the new voltage.

The results were compared with triangular wave to generate PWM signal to control MOSFET.

After determined the V_{ref} the implemented (SMC) algorithm calculate the difference between the acquired PV voltage and the V_{ref} and then, via the boost converter force the PVG to operate at the reference voltage value (V_{ref}) and therefore at the maximum power zone.

$$u = \begin{cases} 1 & S > 0 \\ 0 & S < 0 \end{cases} \quad (14)$$

Stability demonstration:
The stability can be analyzed using the Lyapunov stability method. A positive definite function *V* is defined as:

$$v = \frac{1}{2} S^2 \quad (15)$$

Whose time derivative is :

$$\dot{v} = S\frac{dS}{dt} = S\dot{S} \quad (16)$$

Considering $$\begin{cases} S = e = V_p - V_{MPPT} \\ \dot{S} = \dot{e} = \dot{V}_p \end{cases} \quad (17)$$

2) The Current Controller:

By imposing the inductor current reference, the current controller will assure the fast reference tracking at the same time with delivering the appropriate duty cycles (D).
By introducing an anti-parallel diode for each active power device, a bidirectional buck boost converter is obtained [13].

3) Inject of two sources to inverter:

According to the sign convention, the laws of physics require the power balance in the system described by:

$$P_{dc} = P_{PV}(t) + P_{Bat}(t) \quad (18)$$

The relationship that connects the output voltage and the output current of the inverter is given by the following expression:

$$V_{DC} = L\frac{di}{dt} + Ri + C\int i \quad (19)$$

VI. Simulations:

In order to investigate the performance of the proposed controls algorithms, a numerical simulation was made in the environment Matlab/Simulink. The system characteristics and controller parameters are summarized in table 1.

The main characteristics of the PV array, designed using PV-TD 195HA6 modules connected in a proper series-parallel, making up a peak installed power of 1.2 kW.
As there is DC-DC converter between the PV generator and the inverter, the PV array configuration should be chosen such that the output voltage of the photovoltaic generator is adapted to the requirements of the inverter in case, lacks voltage takes on the voltage of battery.
In this case a 220V has been chosen, so the inverter would need at least 110V DC bus in order to be able to operate correctly.
The minimum number of modules connected in series should be determined by the value of the minimum DC bus voltage and the worst case climatic conditions. The PV array was found to require 3 series connected modules per string.

Table I: Electrical specifications for the solar module PV-TD 195HA6

Parameter Symbol	**Value**
Maximum Power *Pm*	183W
Short circuit current *Isc*	8.48A
Open circuit voltage *Voc*	30.6V
Maximum power voltage *Vm*	23.9V
Maximum power current *Im*	7.66A
Number of parallel modules N_p	2
Number of series modules N_s	3

To demonstrate the design results. The solar radiation changes its value as follows: 600W/m² to 1000W/m² at t =5 and decrease to 800W/m² at t=8s.In same time, the temperature has variable values as follows: 317K to 329K and decreasing to 323K .Figures 6 to 13 give the simulation results when the reference of the DC bus voltage is =110V .

Figures 10, 11and 12, show that the SMC method deliver the suitable duty cycle signal used to drive boost converter to reach the MPP very quickly and with an excellent performances and high accuracy even with variations of atmospheric conditions.
The specifications used for the battery are given below.
Battery type: TUDOR battery
Nominal Voltage: 2 V
Nominal capacity: 800Ah
Figure 13 show the power source selector, the battery comes into operation to the power inverter system when the electrical power demanded by consumers is higher than the electrical power obtained from the PV generator; otherwise the PV system feeds directly the load

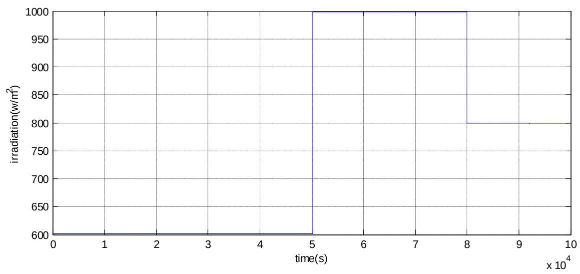


Fig. 8. Irradiation variation

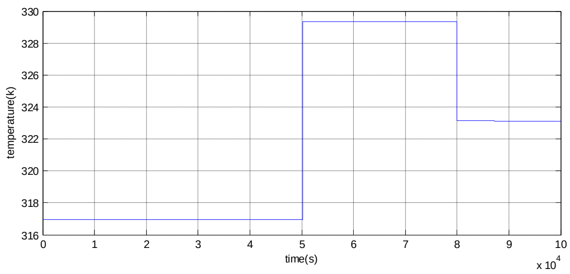


Fig. 9. temperature variation

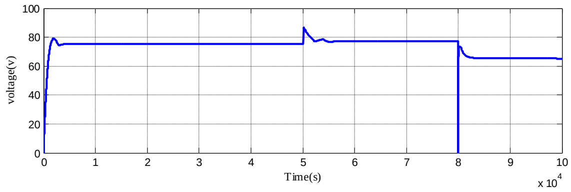


Fig. 10. PV array voltage using sliding mode controller

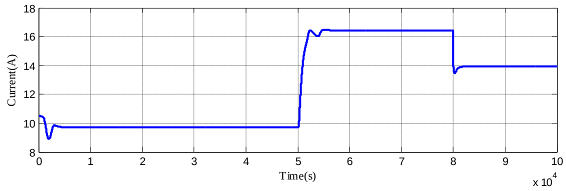


Fig. 11. PV array current using sliding mode controller

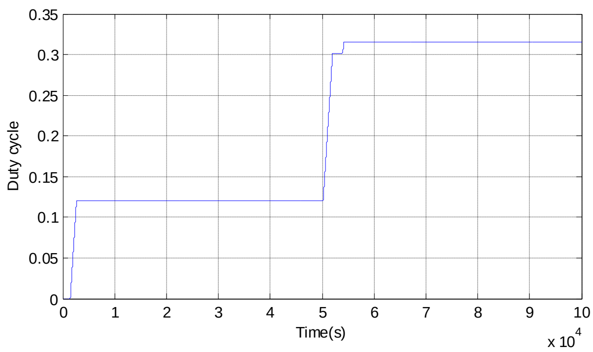


Fig. 12. The Duty cycle sliding mode tracker output signal

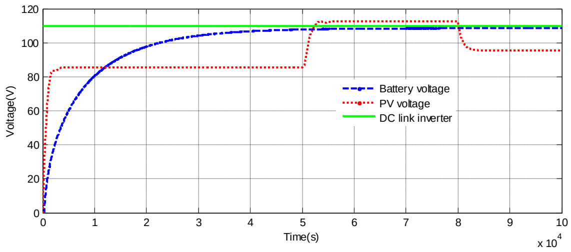


Fig. 13. The DC link voltage

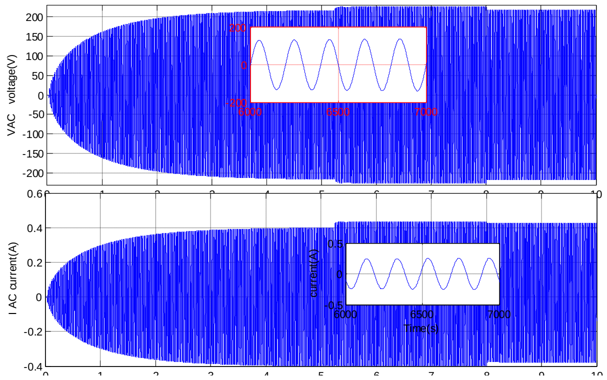


Fig. 14. The Simulation results (a) Inverter Output AC Voltage, v_{AC}, (b) Inverter Output AC Current

VII. CONCLUSIONS

This paper has focused on standalone photovoltaic system was treated. An efficient SMC controller was placed in order to boost the energy flow to PV module. A model using 'Simulink-Matlab' software, which is a high level language and interactive environment, enables the prediction of the system intensive tasks in a fast and precise manner.

According to the results of simulation, we can confirm the feasibility of the architecture the combination of the PV system with battery, and the possibility of carrying out this topology in an autonomous system PV, but we must optimize it to reach good mode of operation.

In this study, we tried to use a bidirectional DC converter with battery not for store energy but for adjusting the power input of a PV inverter. This last is important for equipment that ensures more functionality in PV systems.

REFERENCES

[1] O. Edenhofer,R.Pichs"Renewable energy and sources climate change mitigation", Cambridge University Press , 2012, pp687-1075.

[2] M. Farhat, O. Barambones, L. Sbita, "Efficiency Optimization of a DSP-Based Standalone PV System using a stable single input Fuzzy Logic controller," Renewable & Sustainable Energy Reviews, Elsiver publisher, vol. 49, 2015, pp. 907–920.

[3] http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa&lang=fr.

[4] V. Salas, , E. Olías, A. Barrado, A. Lázaro," Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems", Solar Energy Materials and Solar Cells, vol 90,2006, Pages 1555–1578.

[5] M. Farhat, O. Barambones , L. Sbita, "Real- Mechlouch R, El Jery A, Ben Brahim A "choix d'un modèle d'ensoleillement et détermination des inclinaisons optimales des capteurs héliothermiques pour la ville de gabes en tunisie "Revue des Energies Renouvelables, Vol.6, 2003.

[6] N. Achaiboua, M.Haddadib, A.Maleka ," Modeling of lead acid batteries in PV systems", Energy Procedia ,Vol 18 ,2012,pp 538 – 544 Time Efficiency Boosting for PV Systems using MPPT based on sliding mode," Energy Procedia, Elsiver publisher,vol.75,2015, pp.361–36.

[7] M. Farhat, O. Barambones, L. Sbita, "Efficiency Optimization of a DSP-Based Standalone PV System using a stable single input Fuzzy Logic controller," Renewable & Sustainable Energy Reviews, Elsiver publisher, vol. 49, 2015, pp. 907–920.

[8] M. Farhat, O. Barambones , L. Sbita, "Real-Time Efficiency Boosting for PV Systems using MPPT based on sliding mode," Energy Procedia, Elsiver publisher, vol.75, 2015, pp.361–36.

[9] Hamed Mashinchi Mahery, Ebrahim Babaei," Mathematical modeling of buck–boost dc–dc converter and investigation of converter elements on transient and steady state responses", Electrical Power and Energy Systems , , Elsiver publisher ,vol 44 ,2013,pp 949–963.

[10] Nabil A. Ahmed*, A.K. Al-Othman, M.R. AlRashidi, " Development of an efficient utility interactive combined wind/photovoltaic/fuelcell power system with MPPT and DC bus voltage regulation," Electric Power Systems Research, Elsiver publisher, vol. 81, 81 2011,, pp. 1096–1106.

[11] Chen-Chi Chu a, Chieh-Li Chen, "Robust maximum power point tracking method for photovoltaic cells: A sliding mode control approach", Solar Energy, Elsiver publisher, vol. 83, 2009, PP 1370–1378.

[12] Tamal Biswas, Prof. G K Panda2, Prof. P K Saha," Design of BoostConverter of Sliding Mode Control Powered by PV Array", International Journal of Advanced Research in Electrical Electronics and Instrumentation Engineering,Vol. 4, Issue 5, May 2015,pp2320 – 3765

[13] Andersen,G.K. Blaabjerg, F.," Current Programmed Control of a Single-Phase Two-Switch Buck–Boost Power Factor Correction Circuit" Industrial Electronics, IEEE Transactions ,Vol 53,2006, 263 - 271 .