A Novel Analog Circuit Design for Maximum Power Point Tracking of Photovoltaic Panels

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Abstract—A new analog technique is proposed in order to track the Maximum Power Point (MPP) of PV panels. The proposed technique uses the well-known simple functions of electronic circuits. The proposed technique is validated by applying it to Boost based off Grid PV system. The simulation of the PV system was done on the circuit oriented simulator Proteus-ISIS. A good efficiency of the analog technique (more than 98%) was registered. The variation of irradiations was introduced in order to study the robustness of the proposed analog MPPT technique.

Keywords—Analog technique , Maximum Power Point Tracking (MPPT), Photovoltaic system (PV).

I. INTRODUCTION

Currently, the production of domestic and industrial energy is based, in large part, on a limited resource: oil. Oil sources are becoming more and more rare, while the energy demands of the world rise continually. Since this form of energy covers a large part of the current energy production, it is necessary to find another solution to take over. The imposed constraint is to use an energy source that is economical and less polluting because the protection of the environment has become an important point [1-3].

The search for alternative energy resources has therefore become a crucial issue these days. Many scientific researches has been carried out, not only in the field of nuclear energy production, but also in the sector of unlimited energy sources, such as wind power generation and energy transformation. In the latter case, the design, optimization and realization of photovoltaic systems are topical issues since they lead to a better exploitation of solar energy [2].

These photovoltaic powers generating systems can be operated in different Places: electrification of isolated sites, installation in buildings or direct connection to Network of electricity, ...

A major problem with PV systems is to realize transfer of maximum power from PV generator to load. For several years, many MPPT control methods have been developed and implemented, like Fuzzy Logic Method [4,5,6,10], perturbation and observation (P&O) method [5,6,8], and Incremental Conductance (Inc.Con.) method [7, 9-11]. These techniques are generally complex and expensive to implement [4-7-12]. They differ in several aspects like complexity, range of effectiveness, cost, convergence speed, implementation hardware, required sensors, popularity, plus other respects. However, these techniques are digital implementations.

Alternatively, the MPPT can be implemented by analog circuits [13-14]. The potential benefit from analog solution is the MPPT can be integrated with DC-DC controller such that “plug and play” can be expected for many low power PV applications. In fact, integration of certain functions into a normal PWM controller chip is the most desirable way for special applications to reduce the implementation complexity and system cost.

In this paper, a new analog MPPT technique suitable for PV system applications is presented and validated by simulations.

II. SOLAR CELL CHARACTERISTICS AND PV MODULE

Solar cell is the main building block of PV arrays, which consist of many photovoltaic cells linked in parallel/series manner for each module. A PV cell can be modeled from the equation defining the static behavior of the PN junction of a conventional diode. Thus, *Fig.1* illustrates the electrical equivalent scheme of a real PV cell. In this equation, the short-circuit current and the various resistors modeling the losses due to the connection are taken into account. Thus, in static state, the behavior of a PV cell made up of a silicon-based PN junction can be described by equation (1) [14-16].

$$I_{pv} = I_{PH} - I_D - \left(\frac{V_D}{R_P}\right) \quad (1)$$

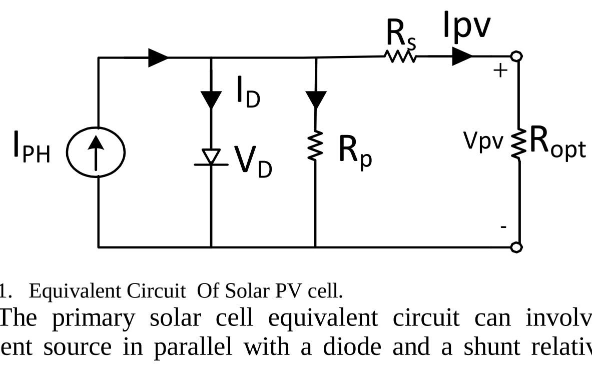

Fig. 1. Equivalent Circuit Of Solar PV cell.

The primary solar cell equivalent circuit can involve a current source in parallel with a diode and a shunt relatively large resistance (R_p), in addition to a usually small parasitic series resistance (R_s). However, R_p is mainly attributed to the p-n junction, the non-linearity, and impurities near the junction [15-16].

The current I_D is given by the Shockley equation:

$$I_D = I_0\left[\mathrm{Exp}\left(\frac{qV}{nKT}\right) - 1\right] \quad (2)$$

Where I_0, q, k and T are respectively the cell's reverse saturation current, the charge of electrons, the Boltzmann's constant, the cell's working temperature. n is the diode ideality factor and V is the voltage across the diode terminals.

The PV module characteristic has a current boundary called short circuit current $I_{sc} = I_{PH}$ and a voltage boundary called open circuit voltage V_{oc} given by the following equation.

$$V_{oc} = \frac{nKT}{q}\left[\ln\left(\frac{I}{I_0}\right)\right] \quad (3)$$

The PV module can also be characterized by the maximum power point where the product of its voltage (V_{mp}) and its current (I_{mp}) is at its maximum value. The maximum power output is derived by finding the local maxima of the product of PV output current and voltage:

$$\frac{d(V*I)}{dV} = 0 \quad (4)$$

and

$$V_{mp} = V_{oc} - \frac{KT}{q}\left[\ln\left(\frac{V_{mp}}{nKT/q} + 1\right)\right] \quad (5)$$

The goal for a solar direct electricity generation system or photovoltaic system is to provide high quality, reliable, and green electrical power. Usually a number of PV modules are arranged in series and/or parallel combinations to meet the output energy requirements. The series connection increases the module's voltage whereas the parallel connection increases its current [16].

At the temperature 25°C and irradiation of $1000 W/m^2$, Table I shows the electrical characteristics of the used PV module given by manufacturer data sheet [17].

TABLE I. TYPICAL ELECTRICAL CHARACTERISTICS OF A PV MODULE JASOLAR

Characteristics	Specifications
Maximum power rating	265 W
Open circuit voltage (V_{oc})	38.38 V
Short circuit current (I_{sc})	8.8 A
Maximum power voltage (V_{mp})	31.24 V
Maximum power current (I_{mp})	8.48 A

III. Operation Principle of the New Analog MPPT Controller

Maximum Power Point Tracking (MPPT) is the important factor in PV systems to maintain maximum power output. It is the component that tracks the maximum power point of the PV panel's curve.

The problem addressed by MPPT techniques is to maintain the output voltage V_{MPP} and current I_{MPP} at which a PV array should operate to produce the maximum power output P_{MPP} under controlled conditions of irradiation and temperature.

Fig.2 shows the current-voltage (I-V) and power-voltage (P-V) characteristics of a typical solar cell. For overall optimal operation of the PV system, the load operating point has to match the PV array's MPP.

Here, the design of a photovoltaic system equipped with a new analog Maximum Power Point Tracking (MPPT) technique is studied. Its main parts are the switch-mode DC-DC converter, the control system, and the tracking system. Proteus-ISIS simulation tool was used to show proposed analog technique performance [18].

A. Typical PV System using Proposed Analog MPPT Controller.

The two main categories of PV systems are grid tie and stand alone. In our case, we have chosen to develop the analog MPPT controller on a simple and classical stand-alone PV system. Specific equipments are required to control, transfer, distribute, and store the energy produced by the PV arrays. *Fig.3* shows the basic block diagram of a typical off grid PV system that has been used in our application.
The different blocks constituting the system are:

- The PV panels.
- Load; in our case a simple impedance.
- DC-DC boost power converter. In this case the output voltage is higher than the one delivered by the PV panel. The converter involves one controlled switch (Mosfet or IGBT).

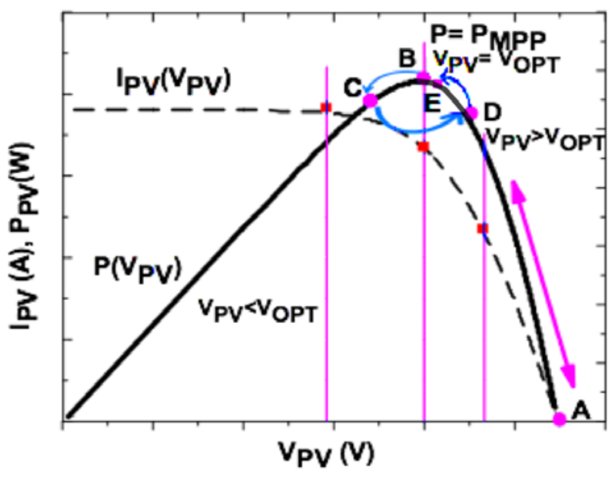

Fig. 2. I-V, P-V characteristics of a solar cell showing MPP.

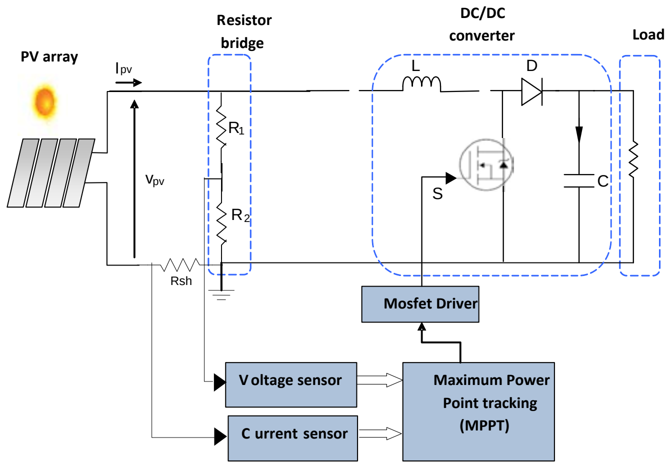

Fig. 3. Block diagram of a the proposed photovoltaic system.

The semiconductor device is controlled by a variable frequency and duty cycle (α) driving signal.

- Analog MPPT controller. Allow the track of the maximal power point of the PV array, which depends on climate conditions [19]. Consequently, the controller guides the power point of the PV panel to converge to its maximum. Its operating principle is based on the automatic variation of the duty cyclic (α) to continuously maximize the power at the PV array output.

The detailed diagram of the photovoltaic technique is presented in *Fig.4*. This controller uses the voltage and current of Photovoltaic panels to calculate the instantaneous power delivered by Panels.

- A shunt resistor (R_{sh}) used as a current sensor of the PV panel.
- A voltage divider composed by two resistors "R_1 and R_2" used to obtain an image of the voltage across PV panels.
- An analog multiplier is used to calculate the instantaneous output power delivered by the PV panels.
- The block P_{ref} generator produces a reference signal that represents the reference power. This signal has a constant magnitude, adjustable period T_s and constant T_{off} (few millisecond). The slope rates values of the P_{ref} waveform can be modified depending on system response time (*Fig.7*). The generator function is based on NE555 integrated circuit.
- A comparator (2) compares the really generated power (P_{real}) and the reference power signal (P_{ref}).
- An hysteresis (2) used to detect the Maximum Power Point and to control the Hold circuit, it's output commute to (+15V) when the comparator (2) output reach ε3 indicating the failover of the panels operating point to the left side of the P(V) characteristic (point C in *Fig.2*).

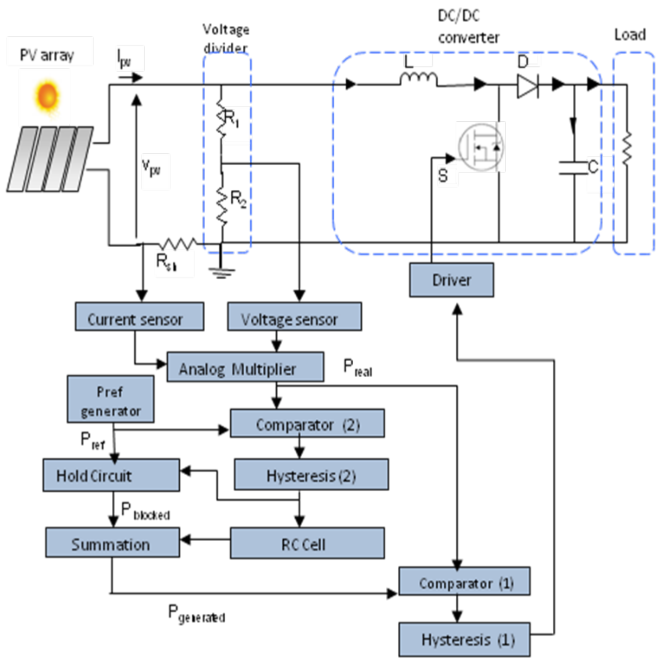

Fig. 4. The detailed synoptic diagram of the whole photovoltaic technique

- A hold circuit which can block the value of the reference signal (P_{ref}) and gives $P_{blocked}$ signal. The blocked value is slightly higher than the MPP of the panels arrays. When P_{ref} is blocked, the panel operating point is in (C).
- An RC cell which generates a pulse when the maximum power is reached (define the values of ΔV2 and (ΔV1+ε3) of the generated power shown in *Fig.6*).
- The summation block produces $P_{generated}$ from $P_{blocked}$ and the RC circuit outputs. This bloc output allows to bring the panel operating point from (C) to (D) and to obtain, in the steady state, the optimal value of the power detected by our technique (point E in *Fig.2*).
- A comparator (1) calculates the difference between P_{real} and $P_{generated}$ signals.

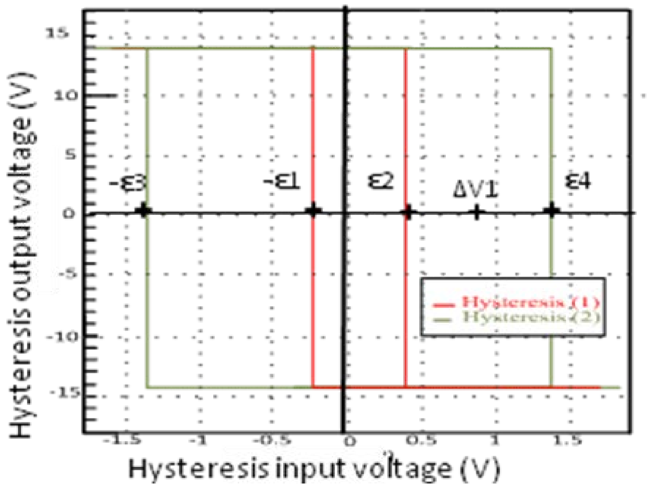

Fig. 5. The transfer function of the Hysterisis (1) and the Hysterisis (2)

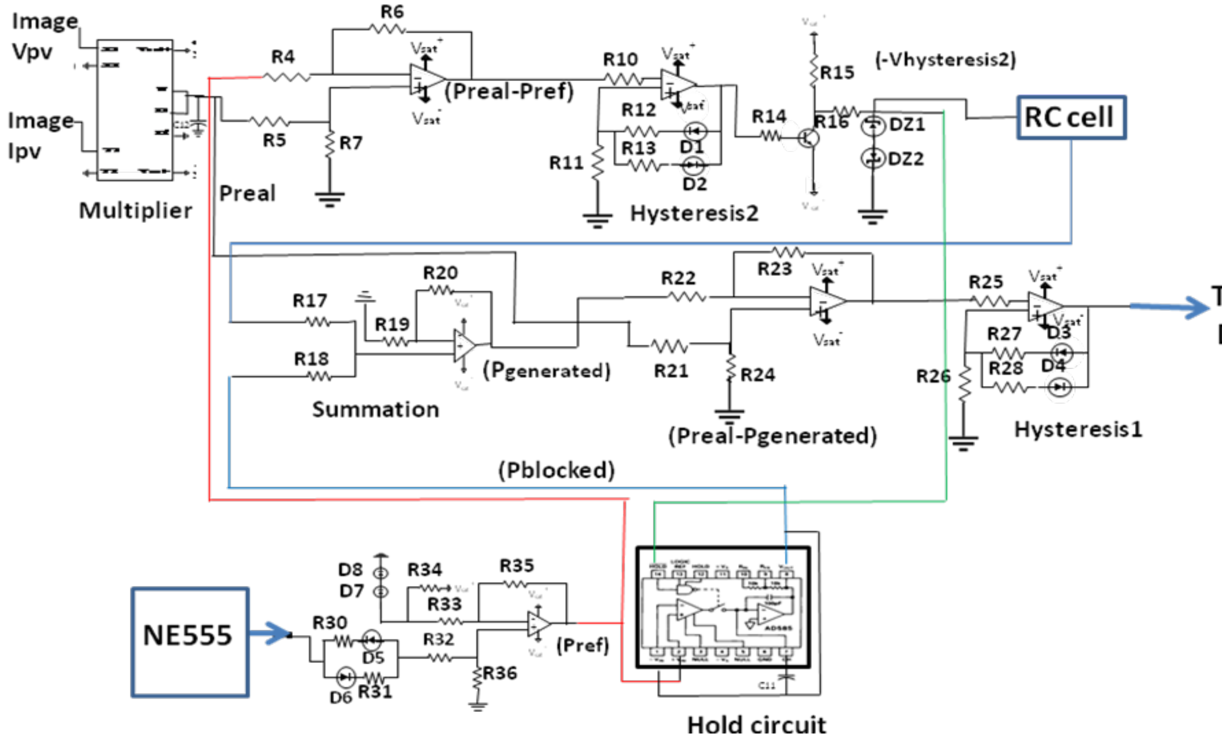

Fig. 6. The proposed analog MPPT technique circuit.

- The hysteresis (1) is used to control the real power P_{real} close to the generated power waveform $P_{generated}$ which is considered as the optimal power of the PV panel deduced from our technique. If the difference between the real and generated power reach the upper/lower limit, the power is forced to decrease/increase. The hysteresis control has the benefit of very quick response, variable switching frequency, and simpler process than other control techniques. This signal is injected to MOSFET transistor of the DC-DC boost converter through the driver.

Fig. 5 shows the transfer function of the Hysteresis (1) and the Hysteresis (2) blocks.

Fig. 6 shows the electrical circuit corresponding to the proposed analog MPPT technique. The circuit contain mainly one multiplier, a precision timing circuit, a Hold circuit and six Operational Amplifiers.

B. Principle of the Proposed Analog MPPT Controller

The majority of MPPT techniques attempt to vary PV current I_{MPP} in order to match the maximum power point, or to find the PV voltage that results in the maximum power point V_{MPP}.

Fig. 7 shows the principle of the proposed analog technique using powers waveforms. The proposed analog technique is based on the generation of a reference power signal (P_{ref}) to be followed by the PV panel's real power (P_{real}) while P_{real} is lower than the maximum power P_{max} (between A and B of the power static characteristic P(V)). $P_{generated}$ and $P_{blocked}$ signals are equal to P_{ref} while the error between P_{ref} and P_{real} is within Hysteresis 2 tolerance band. The P_{real} signal is regulated to $P_{generated}$ signal by Hysteresis 1 band.

When the reference signal P_{ref} increase and if the actual real power couldn't pursue this signal (the maximum power P_{max} is reached), the panel operating point will be brought to the left side of the P(V) characteristic (point C). At this situation, the Hysteresis (2) act on the Hold circuit in order to block the P_{ref} signal and obtaining the signal $P_{blocked}$.

In the above situation, the real power can't be regulated to the blocked value which is slightly higher than the maximum power P_{max} and the panel operating point will decrease to zero of the left side of the P(V) characteristic (the increase of boost duty cycle decrease power in the left side of the P(V) characteristic).

In order to avoid the above behavior of the operating point, the $P_{generated}$ signal is created in order to regulate real power to this signal in the rest of the time T_{on}. In fact, the panel operating point should be brought, from point (C), to the right side of the P(V) characteristic (point D). A first order pulse (generated by the RC cell bloc) is declined from the blocked signal $P_{blocked}$ and $P_{generated}$ signal is obtained. Since the P_{real} signal is regulated to the $P_{generated}$ signal by Hysteresis (1), the panel operating point goes within its tolerance band (point D). During this transition, the operating point pass by the maximum power value (B).

The regulated real power pursue $P_{generated}$ until the operating point (E) slightly lower than the maximum value P_{max}.

The hysteresis bands and first order pulse magnitude are chosen so that the operating point (E) is below the operating point (B) in the right side of the P(V) characteristic.

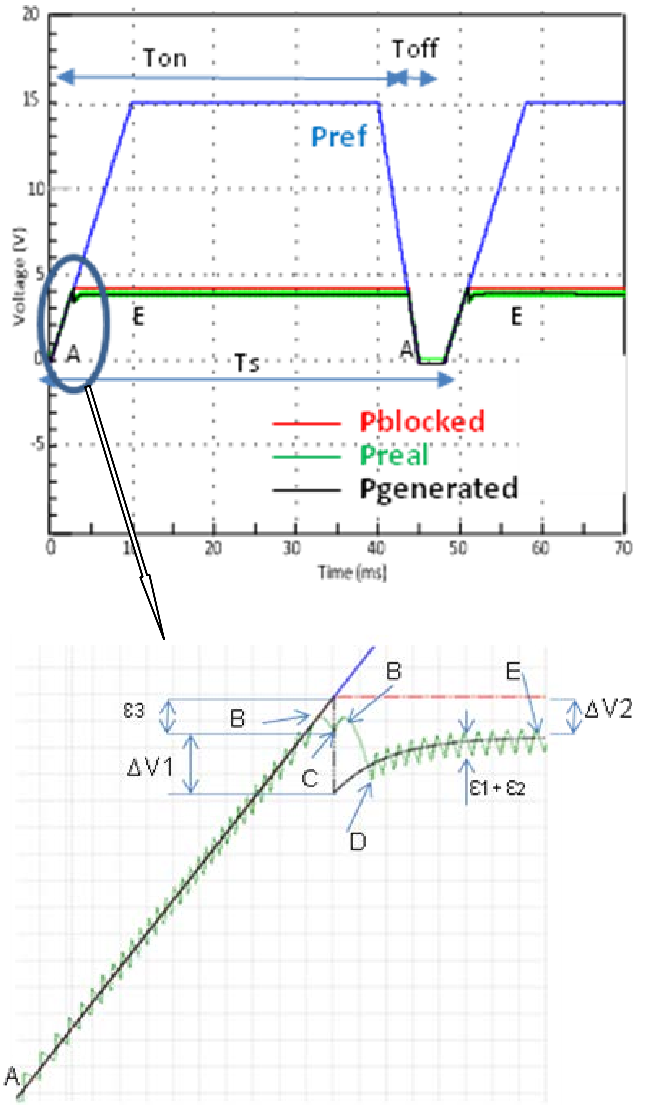

Fig. 7. Different Power waveforms evolutions and the corresponding panel operating point in P(V) characteristic.

At the end of the (T_{on}) and when the P_{ref} signal decrease and become lower than actual power P_{real} ($\varepsilon 4$ is exceeded), the Hysteresis 2 react and cancel the hold bloc control signal, the $P_{generated}$ and $P_{blocked}$ signal become equal to the reference signal and the regulated actual power P_{real} decrease too and reach the operating point (A). The initialisation phase was then started and will continue during the time T_{off}.

The value of ΔV_2 is fixed by the RC cell circuit and it is choosen given by the following condition.

$$\Delta V_2 - \varepsilon_2 > \varepsilon_3 \tag{6}$$

This condition is necessary to be sure that the operating point of the PV panels is kept in the right side of the maximum point of the P(V) characteristic.

The used circuit of the RC cell bloc is given by *Fig. 8*. The input signal of this circuit is the inverse signal ($-V_{Hysteresis2}$) of the Hysteresis 2 bloc output.

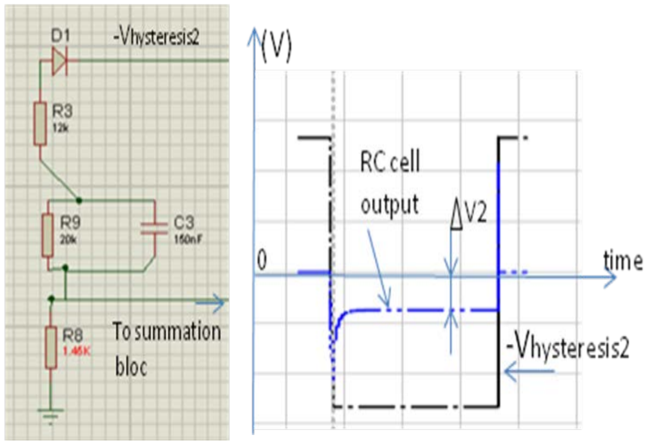

Fig. 8. The RC cell Bloc circuit and it's output voltage waveform.

C. Simulation Results.

The proposed MPPT technique, power converter and PV arrays models are implemented in the Proteus-ISIS circuit oriented simulator. For different irradiance conditions, the different voltage waveforms corresponding to the above mentionned power are registered and shown in *Fig. 9*. It's clear that the real power converge, during the steady state, to a value (E) slightly lower than the array paximum power (B). The difference between the generated preal power and the optimal panel power contribute to the performance assessment of the proposed analog technique.

The efficiency of the proposed MPPT technique was computed for different T_{on} values. *Fig. 10* shows the evolutions of this efficiency as a function of radiation intensity for two T_{on} values (T_{off}=4ms). The effenciency was calculated by the following equation.

$$\eta = \frac{\int_0^{Ts} P_{real}}{\int_0^{Ts} MPP} \tag{7}$$

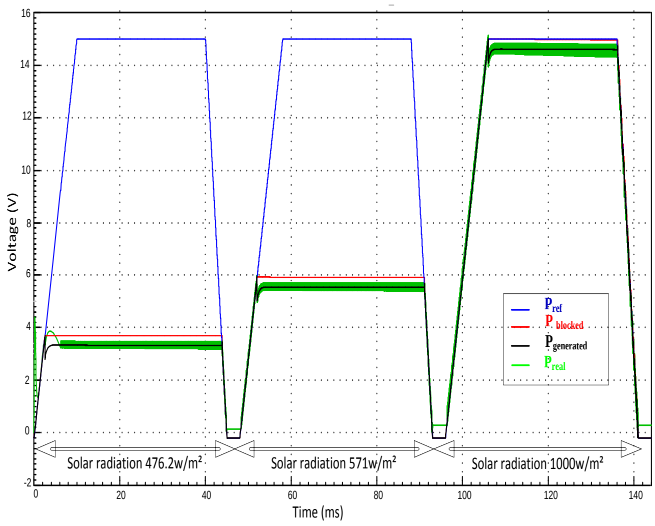

Fig. 9. Tracked maximum power under variable solar radiation .

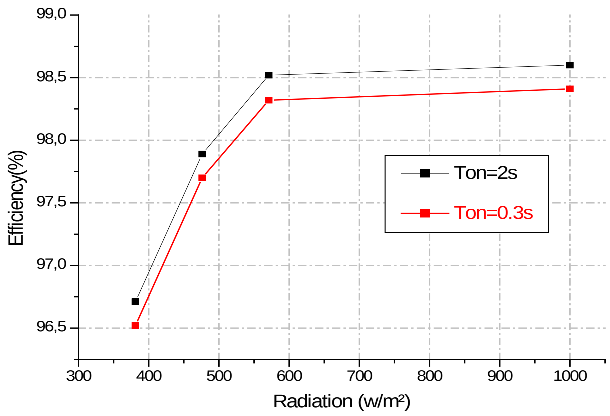

Fig. 10. New MPPT technique efficiencies for unipolar input reference Pref.

In order to increase the efficiency of the proposed analog MPPT technique a bipolar (+15V/-15V) P_{ref} signal is used. In fact, when the variation of P_{ref} become equal to 30V, the relative error generated by the proposed MPPT technique, in order to detect the optimum power, decrease. *Fig. 11* shows the change of the MPPT technique's efficiency as a function of irradiation. We notice that the maximum efficiency reach 99.3% at 1000W/m^2. In literature [19-20-21], the various classical P&O or conductance incremental algorithms yield MPPT efficiency between 95% and 98%.

Beyond a T_{on} duration equal to 2s, the efficiency of the proposed technique tends to 99.5%.

In the proposed analog MPPT technique, we obtained a good efficiency of the technique compared to the analog techniques proposed in literature [22-23] (varying between 95% and 99.5%). If we compare our technique to the best one, allowing a comparable efficiency, published in literature, we can find that the proposed technique use a low number of discrete devices and only one multiplier circuit is used. The good technique efficiency associated to a low number of electronic functions can be promising and the integration of the proposed analog MPPT solution can offer a interesting in a IC circuit.

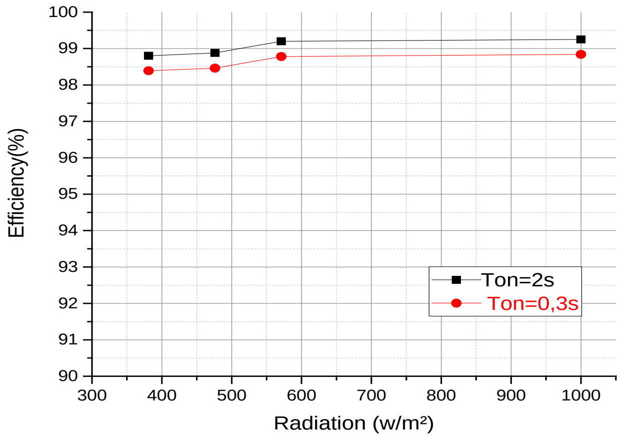

Fig. 11. Proposed MPPT technique efficiency as a function of irradiation when the reference power signal (Pref) vary between -15V and 15V.

IV. Conclusion

A new technique to track the maximum power point operation using analog MPPT controller is proposed in this report. The proposed MPPT control strategy has the ability of fast tracking of the MPP for PV systems. It uses DC -DC boost converter. Through simulation by Proteus ISIS, the accuracy and feasibility of the proposed method was validated. The idea proposed showed its accuracy to detect the optimal generated power by the PV panels. An improvement of the technique efficiency, by using a bipolar voltage of the reference P_{ref} signal, was registered. The efficiency of the analog MPPT technique reach values higher than 99%.

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