Energy Transfer Optimization in Photovoltaic Conversion by the Maximum Power Point Tracking

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ABSTRACT
Of the energy source point of view, for a photovoltaic array (GPV), the power production varies strongly according to insolation level; temperature and nature of the load on which the GPV debits, and according to the characteristics of the latter, a very strong variation can be to find between the potential power of the generator and that really transferred to the load in direct connection mode. Therefore, in order to extract at every moment the maximum of power generated by the GPV and to transfer it to the load, it must be equipped with a switch-mode converter which plays the part of interface between the two elements. This switch-mode can be a Boost (Step-up) or Buck (Step-down) converter according to the applications.

General Terms
Photovoltaic power generator, Optimization system, Power, Regulation, inverter efficiency.

Keywords
Photovoltaic, Regulation, Extreme command, Optimization, Power.

1. INTRODUCTION
Studies show that a solar panel converts 20-25% of energy incident on it to electrical energy [14]. A Maximum Power Point Tracking (MPPT) algorithm is effectively necessary to use solar array power. The objective of MPPT is to ensure that the system can always harvest the maximum power generated by the PV arrays.

There are two main groups of MPPT: those that use analog circuitry and classical feedback control, and others that use a microprocessor to maintain control of the maximum operating point [11].

In this paper, we chose the digital control. The digitally controlled MPPT systems have the advantage that a power point tracking algorithm will not be influenced by changes in temperature and therefore will always be very reliable.

2. THE MPPT ROLE
2.1 Definition:
MPPT control is a functional organ of the PV system which makes it possible to seek the optimal operating point of the GPV which depends on the weather conditions and the load variation [10,12]. The regulation concept is based on the automatic variation of the duty cycle α to the optimal value so as to get continuously the maximum power from the PV array.

2.2 Operation principle
Let's take as example, for an incidental power P_1, the optimal power transferred to the load could be maximal only for well defined duty cycle: α_{1opt} (P_{PM1} point on figure 1). If the incidental power changes to P_2, the new maximum power point is P_{PM2}, but the operational point of the GPV is P_F. To converge towards new point P_{PM2}, it is necessary to adjust the duty cycle α with the value α_{2opt} [13]. Therefore, in an independent and autonomous PV system, this regulation must be automatically realized in order to seek the optimal operation point.

2.3 Evolution of the GPV operation point
The comparison between two powers (P_1) and (P_2) respectively measured at the moment (t) and (t-1) served us to seek the maximum power point (figure 2). If the derivative is positive ($P_1 < P_2$), that means that we approach the PPM, and if the derivative of the power is negative ($P_1 > P_2$), that means that we exceeded it.

Thus with the system starting up, the research for PPM is done progressively, by seeking the first maximum.

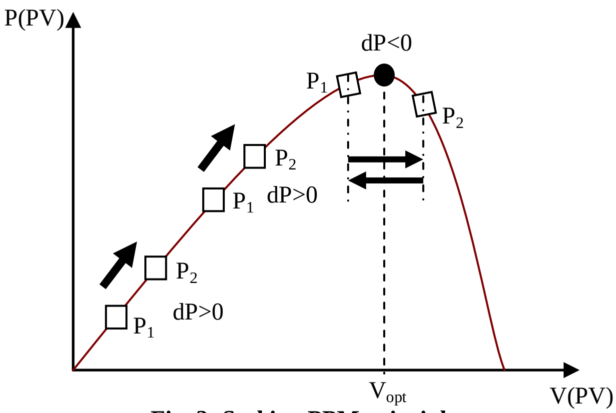

Fig. 2: Seeking PPM principle

3. STUDY AND DESIGN OF A REGULATOR OF CHARGE/DISCHARGE OF A BATTERY PROVIDED WITH A DIGITAL MPPT CONTROL
The objective of this paper is to build an MPPT to charge a 24-volt lead acid battery by using a field wired 100 Watts PV array. The concrete objectives that we want to reach by this digital realization are the following:

- Reduction in production costs compared to analog MPPT.
- Reduction of the number of component used for the implementation.
- Reduction in the total volume of the printed circuit board.
- Reduction in the overall consumption of energy.

P_{PV}

3.1 Definition of PV Module and Estimate of Produced Energy

The GPV must provide all the power consumed by the system, by taking in account the losses on all the circuit. The surplus is stored in an accumulator battery to be able to have it during the periods when the sun does not appear [11].

Since our load is a 24V-lead-acid battery, only one PV module is necessary; we used the NP100G12 of the company NAPS which can deliver an electric power of 100W under an incidental radiation of $1000W/m^2$.

And concerning the energy produced by this module in one day it is initially necessary to know the daily received energy which depends on the number of sunning hours [7].

For an average sky, to the site of Tlemcen (North-western of Algeria) and for an inclined PV module (β =34°) directed towards the south, a simulation work gave the following results [Mr. C-ZIDANI URMER Laboratory, Tlemcen university]:

Table I. Estimate of daily received energy within the site of Tlemcen

	Ejs(Wh/m2)	EjD(Wh/m2)	EjG(Wh/m2)
Winter	4188.6	723.09	4911.7
Autumn-Spring	6138.4	1090.6	7229.6
Summer	6159.7	1309.6	7469.3

TABLE II. Estimate of the daily electrical energy produced by the GPV.

	EjG(Wh/m2)	Neq (h/j)	Eélec(Wh/j)
Winter	4911.7	4.91	491
Autumn-Spring	7229.6	7.23	723
Summer	7469.3	7.47	747

Starting from these two tables we can conclude that the site of Tlemcen, where the capacity operating by the module exceeds on average the 650 WH/d, is a good site for our application.

3.2 Hardware Design

The most critical section of the power tracker is switching converter section. The DC/DC converter is generally selected according to the wished input or output voltage; the tracker is conceived either to increase the output voltage (Boost converter) or to decrease it (Buck converter) [5]. In our case, our generator will be able to function with its maximum power only around 16.7V and since we must have an output voltage higher than the battery voltage (24V), we chose a Boost converter type, in more it is easier to realize, and maximizes the effectiveness of the GPV - especially in the cloudy days-[6] and to guarantee a continuity of the current (since the tracker is primarily a commutation stage). Moreover, it presents the advantage of having a diode at the output. This diode placed right before the battery could thus be used like a blocking diode (Figure 3).

To determine the characteristics of the power circuit is a critical section in our construction. Admittedly, very unsuited component can logically prevent an optimal operation of this power card and can cause losses which we want to avoid them as a measure of economy.

In all calculations which will follow, the extreme case will be considered. We will suppose that the converter is always effective at 100% [3]:

$$P_{in} = P_{out} \quad (1)$$

thus : $$V_{in} * I_{in} = V_{out} * I_{out} \quad (2)$$

with : $V_{in} = 16.7$ v, $I_{in} = 6$ A , $V_{out} = 24$ v

Starting from these two equations and by using the catalogs of the various manufacturers of the electronics components in order to facilitate the choices between several types of components; we can determine the optimal values of the components which we will use in our realization (Table III)

3.3 Implemented Algorithm

In the algorithm implemented in our PIC we are interested directly in the variations of the power according to the voltage; the method applied is equivalent to the incremental conductance method (Figure5) [10,13] but differs nevertheless on some points. The conductance is a relatively physical parameter known [10, 12]:

$$G = I / V \quad (3)$$

The incremental conductance is much more rarely defined; it acts of the variation quotient, between two moments, of the intensity by that of the voltage [11]:

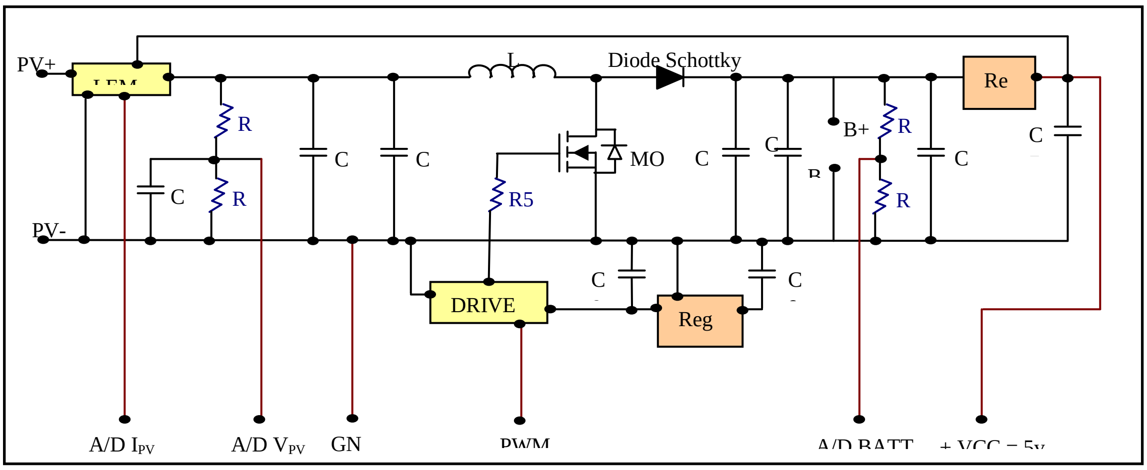

Figure 3. The Boost converter schematic without control section.

$$\Delta G = dI / dV \quad (4)$$

Precisely the power at source output can be written:

$$P = I * V \quad (5)$$

At MPP the slope of the PV curve is 0[1]:

$$dP/dV = 0 \quad (6)$$

From which deriving (5):

$$dP/dV = (I * dV/dV) + (V * dI / dV) \quad (7)$$

$$dP/dV = I + (V * dI / dV) \quad (8)$$

Thus: $$(1/V) * dP/dV = (I / V) + (dI / dV) \quad (9)$$

Then from (3); (4) and (9) we obtain:

$$(1/V) * dP/dV = G + \Delta G \quad (10)$$

And since $V > 0$, we can deduce the key results from the method of the incremental conductance.

From (10) we obtain $dP/dV > 0 \Leftrightarrow G > -\Delta G$

$dP/dV = 0 \Leftrightarrow G = -\Delta G$

$dP/dV < 0 \Leftrightarrow G < -\Delta G$

We deduce the actions easily to be made in the different case on the diagram P = F (V).

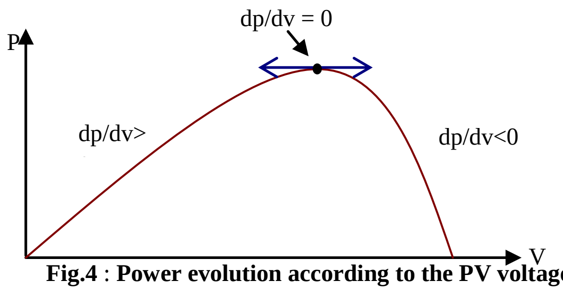

Fig.4 : **Power evolution according to the PV voltage**

Table III. The regulator various components

Designation	2Vcc	12Vcc	24Vcc
Stop charging level	2.35V	14.1V	28.2V
Restart charging level	2.25V	13.5V	27V
Stop using battery level	1.90V	11.4V	22.8V
Restart using battery level	2.15V	12.9V	25.8V

3.4 The Program Explanation

The Incremental Conductance method is chosen as a tracking algorithm for the MPPT. The PIC16F876A microcontroller [15] operates at speed of 4MHz is used to carry out the algorithm. At this speed each instruction set will be executed at 1µ second. The program is written in C and then is compiled by the free version of the compiler “mikroC, mikroElektronika C compiler for Microchip Version: 8.2.0.0”

After the initialization of converters ADC and DAC (PWM) modules, the duty ratio α will be fixed at 0.3 (In the hope of probably getting closer to the PPM by this value at the beginning). After the system starting, the program runs ADC conversion on channel RA1 of the microcontroller to measure the battery voltage. The measured voltage is then compared to the predefined values to determine the battery’s state of charge. If the battery voltage is greater than 27v, the program remains in Stand-by mode during 1 second and then starts again to measure the battery voltage again. And if the tension of the battery is less than 27v, the system starts charged the battery by respecting a recharging with four thresholds [8] (Table IV). In this mode, the method of the incremental conductance will be used.

Table IV. Some technical specifications of the regulator

Component	Type and Parameter
Capacitor	C1 = 47 µF ; C2 = 1000 µF ; C3 = 1 µF ; C4 = 1000 µF ; C5 = 1 µF ; C6 = 0,22 µF ; C7 = 0,1 µF ; C8 = 22 µF ; C9 = 0,33 µF.
Diode Schottky	MBR745; *45 V de breakdown voltage ; 0,57 V threshold voltage.*
Mosfet	*IRFP044N;* V_{DS} =55 V; I_D =53A; R_{DSON} =0.02 Ω.
DRIVER Mosfet	L6384; Vcc = -3 à 14.6V; I_{out} = 25mA
Micro - controller	PIC16F876A (Microship)
Voltage regulator	LM7805 et LM7810 ; Vin=35V ; curant consumption 8 mA.
Voltage divider	R1 = 2,7 kΩ ; R2 = 6,8 kΩ ; R3 = 1 kΩ ; R4 = 3,9 kΩ ; R5 = 6 kΩ

We used PORTA of the PIC (configured in analog input of the ADC module) to read the voltage values V (K) and current I (K) of the GPV, and since the tracking of the PPM is done by calculating G and ΔG at every moment, we will estimate the brusque changes dV and dI by comparing the measured recent voltage values V (k+1) and current I (k+1) with the values V (K) and I (K) measured in the preceding cycle by supposing that:

$$dI \approx \Delta I = I(k+1)-I(k) \quad (11)$$

and $$dV \approx \Delta V = V(k+1)-V(k) \quad (12)$$

Finally, from (3); (4); (11) and (12) we obtain the values of G and ΔG and we can know the action to make since we know the position of our operation point compared to the optimum operation point:

- If $G > -\Delta G$ so we are on the rising part of the power curve and we get closer to the PPM thus we must increase the GPV voltage.
- If $G < -\Delta G$ then we reverse the continuation direction by decreasing the GPV voltage.
- And if $G = -\Delta G$ so the system is already at the PPM in the preceding cycle, and since in this case the GPV voltage will be not change, we obtain $dV = 0$ and the incremental conductance $\Delta G = dI/dV$ is not then defined, we pass to the

variations observation of the GPV current to deduce the actions to be caused to maintain the system at its PPM.

All that is done during 1 minute, after this, by a new testing of the battery state of charge, the tracking algorithm will be then repeated.

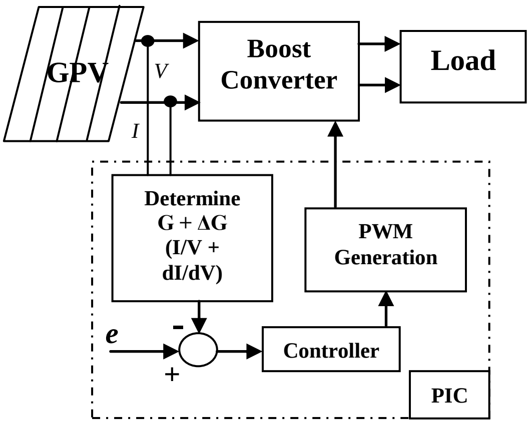

Fig. 5: MPPT by incremental conductance.

4. RESULTS AND DISCUSSION

The reason for which we chose to use the Boost converter in this work it is that we must have an output voltage higher than the battery voltage (24v) whereas the generator voltage is only 16.7 volts.

To check the effectiveness of our Boost, we tested it under various switching modes either by varying the switching frequency of PWM signal or by varying the duty ratio α.

4.1 The Effect of the Switching Frequency Variation on the System Effectiveness

To practically implement the proposed algorithm, we tried to test it at the laboratory, The following experiments show the behavior of the Boost-Converter under different switching frequencies and duty cycle ratios that could affect the power efficiency of the Boost-Converter.

The Figure 6 shows that the system effectiveness reached its maximum for frequencies around 80 KHz, beyond this value we notice that it started to decrease little by little. This is because the switching loss of the MOSFET is proportional to the frequency that driving it.

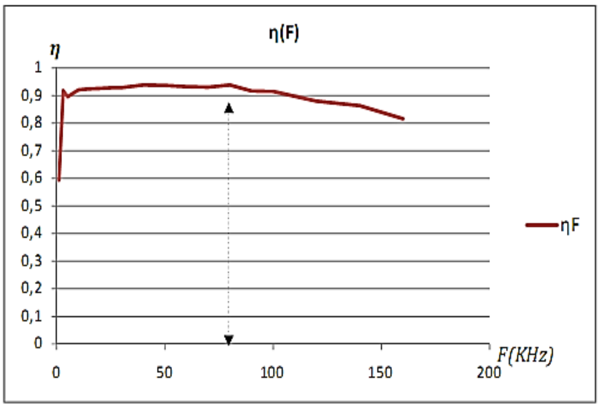

Fig.6 Behavior of the Boost-Converter under different switching frequencies

Also, for frequencies much lower than 10 KHz, the power efficiency decreased rapidly. At this state, the inductor has reached its saturation and it is no longer store energy. As a result, the current in the inductor at this stage is very high [2] and therefore this gives rise to a very high inductor power loss.

4.2 The Effect of the Variation of the Duty Cycle Ratio α on the System Effectiveness

Under the same preceding conditions; we vary the values of the duty cycle ratio α but this time the frequency will be fixed at 80 KHz (it was already shown that it was the optimal frequency to ensure a good effectiveness).

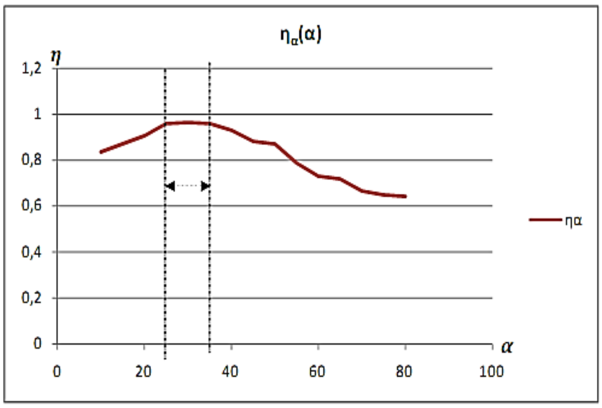

Fig.7: The effect of the variation of the duty cycle ratio α on the behavior of the Boost-Converter.

The results obtained (Figure 7) show a good efficiency and a good stability of the system for values of α ranging between 0.25 and 0.4, beyond these values, the system becomes ineffective and the circuit dissipates a great quantity of heat on the level of the power module (MOSFET and DIODES) which explains this remarkable decrease of the power efficiency.

4.3 Final Test

The efficiency of our regulator was tested by a test-bench including a computer, a data-acquisition: KEITHLEY 2700/7700, one solar panel NP100G12, two lead-acid batteries: GLS6/270Ah-6v, and one lamp 12v/50w [4,5] (Figure8).

Fig.8: Image of the experimental test-bench

Since our load is a battery (where the terminal voltage was fixed by the battery)[4], we have tested our Boost converter where we note that it shows a good stability compared to the variation of the meteorological conditions, and controls well the battery voltage during the charging period. The following figure (Figure9) shows the battery voltage evolution according to time.

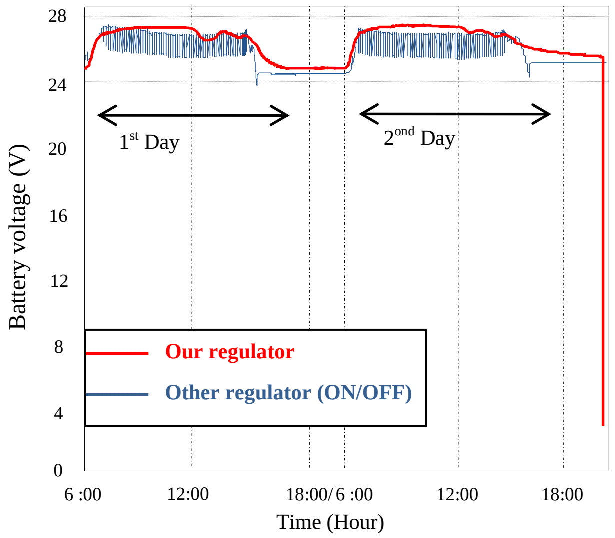

Fig. 9: The battery voltage evolution according to time.

5. CONCLUSION

According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance [13]. Hence our problem of tracking the maximum power point reduces to an impedance matching problem.

In the source side we used a Boost-Converter, which is designed to operate under continuous conduction mode and a microcontroller to control the PWM signals to the Boost-Converter and also to monitoring the battery state of charge. By changing the duty cycle of the Boost-converter appropriately we can match the source impedance with that of the load impedance.

Therefore, it was seen that using Incremental Conduction MPPT technique increased the efficiency of the photovoltaic system by approximately 95%.

6. APPENDIX

GPV:	Photovoltaic generator.
PV:	Photovoltaic array.
PPM:	Maximum Power Point.
MPPT:	Maximum Power Point Tracking.
P_{MAX}	Maximum Power of the GPV.
η :	System efficiency.
α :	The duty cycle.
PWM:	Pulse with modulation.
ADC:	Analogical-digital converter.
DAC:	Digital-Analogical converter.
Reg:	Voltage regulator.
LEM:	Current sensor.
E_{js} :	Direct daily energy.
E_{jD}:	Diffuse daily energy.
E_{jG}:	Global daily energy.
$E_{jélec}$:	Electrical daily energy.
$N_{équ}$:	Equivalent number of sunning hours.

7. REFERENCES

[1] R. Sudharshan Kaarthik"; Modelling, Simulation and Implementation of Low Power Photovoltaic Energy Conversion System", National Institute of Technology Rourkela, Rourkela – 769008, India; 2010.

[2] Mohamed Azab: "A New Maximum Power Point Tracking for Photovoltaic Systems", World Academy of science, Engineering and Technology 44 2008.

[3] B.K. Bose "Modern Power Electronics and AC Drives", Prentice Hall, 2002.

[4] Putting into service of dry charged batteries; OLDHAM France S.A.

[5] Qun Zhao and Fred C. Lee : "High-Efficiency, High Step-Up DC-DC Converters", IEEE Transactions on Power Electronics, Vol.18, No.1 pp.65-73 (2003)

[6] E. Arango, J. Calvente, R. Giral, Asymmetric Interleaved DC–DC Switching Converters: Generation, Modelling and Control, 1st ed., Lambert Academic Publishing, Saarbrucken, 2010.

[7] A. Menti, T. Zacharias, J. Milias-Argitis, Harmonic distortion assessment for asingle-phase grid-connected photovoltaic system, Renew. Energy 36 (2011) 360–368.

[8] C.A. Ramos-Paja, E. Arango, DC/DC pre-regulator for input current ripple reduction and efficiency improvement, Electric Power Systems Research 81 (2011) 2048– 2055.

[9] P. Thounthong, B. Davat, Study of a multiphase interleaved step-up converter for fuel cell high power applications, Energy Convers. Manage. 51 (2010) 826–832.

[10] Jae Ho Lee, HyunSu Bae: "Advanced Incremental Conductance MPPT Algorithm with a Variable Step Size", Seoul National University, Seoul, Korea. 1-4244-0121-6/06/$20.00 ©2006 IEEE.

[11] Thanh Phu Nguyen: "Solar panel maximum power piont tracker" Undergraduate Thesis; University of Queensland.

[12] Hussein, K.H.; Muta, I.; Hoshino, T.; Osakada, M.; "Maximum photovoltaic power tracking: an algorithm for rapidly changing atmospheric conditions" Generation, IEE Proceedings Transmission and Distribution.Vol. 142, No. 1, Jan. 1995 pp:59 – 64

[13] C.R. Sullivan and P.J. Powers, "A high efficiency maximum power point tracker for photovoltaic arrays in a solar-powered race vehicle", 24th annual IEEE Power Electronics Specialists Conference, 1993, PESC'93 Record, 20-24 june 1993, pp 574-580.

[14] Arjav Harjai, Abhishek Bhardwaj, Mrutyunjaya Sandhibigraha: "Study of maximum power point tracking (mppt) techniques in a solar photovoltaic array", Bachelor of Technology in Electrical Engineering; Department of Electrical Engineering National Institute of Technology Rourkela-769008, Orissa

[15] Microchip PIC 16F87X Data Sheet (DS30292C).