

## Evaluation of power losses in a DC-DC Boost converter

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**Abstract.** DC-DC converters are dynamic systems consisting of the passive components. These components under the effect of thermal stress in a PV system generate power losses. The knowledge of these power losses is necessary to evaluate the conversion efficiency of the system. Using the polynomial approximation method, the equations for calculating losses in the different components were determined. The system is implemented under the MATLAB / Simulink software. The results show that for a PV application of 240 W supplied to the load, 18% are lost, only 82% are transferred

**Keywords:** Photovoltaic conversion chain, DC-DC converter, Power losses.

### Introduction

Photovoltaic solar energy comes from the direct conversion of solar radiation into electrical energy through Photovoltaic (PV) cells. Depending on the desired power, these cells are connected in series and or in parallel to give a photovoltaic generator (GPV) [1], [2]. Nevertheless, the production of this energy varies according to the light intensity and the temperature of the cell. On the other hand, [3] states that a direct connection of the PV generator to the load does not guarantee the transfer of the maximum available power. In order to extract the maximum power available at each moment at the terminals of the PVG, the technique classically used is the insertion of a matching stage composed of a DC-DC converter and a MPPT (maximum power point tracking) controller between the GPV and the load [2]. The latter acts as an interface between the GPV and the load by ensuring, through a control action, the transfer of the maximum power supplied by the GPV so that it is as close as possible to the maximum available power. Therefore, several works on photovoltaic systems have led to the development of algorithms to extract the maximum energy from the GPV to increase the system efficiency. Therefore, the main objective of this paper is to shed light on the different losses generated by a converter in a PV conversion chain. To do this, we have based ourselves on the polynomial approximation method and on the manufacturer's data sheets to derive the equations of the losses as a function of the global current. In order to confirm our theory, we proceeded by programming these equations under the MATLAB / Simulink software. The rest of the paper is organized as follows: the block diagram of the studied PV conversion chain is described in section 2 and the loss equations are established in section 3. Section 4 presents the discussions on the obtained results and section 5 concludes the paper.

## Synoptic diagram of a PV conversion chain connected to a DC load

A photovoltaic system consists of four (04) blocks as shown in Figure 2. The first block represents the energy source (PV panel), the second block is a static DC-DC converter, the third block represents the load and the fourth block represents the control system. This MPPT control system is in charge of modifying the cyclic ratio of the converter's switching cell in order to force the panel to deliver the maximum of its energy at each moment.

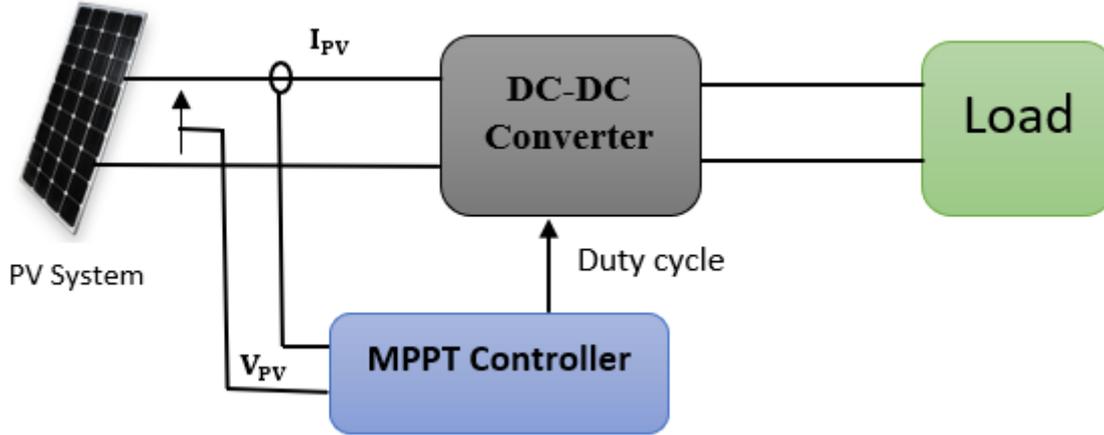


Figure 1: Synoptic diagram of the photovoltaic system

## Global study of the losses for a static converter

As described in the previous section, the constituents of the Boost converter are: MOSFET, Diode, Inductance and Capacitance. The conversion efficiency can be written as:

$$\eta_{\text{Conversion}} = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{P_{\text{in}} - P_{\text{losses}}}{P_{\text{in}}} \quad (1)$$

With  $P_{\text{in}}$  and  $P_{\text{out}}$  the powers respectively at the input and output of the converter,  $P_{\text{losses}}$  the power lost in the converter

### Losses in the MOSFET

The transistor dissipates energy during the firing phase  $W_A$ , the conduction phase  $W_C$ , and the blocking phase  $W_B$  corresponding to a Total energy  $W_T$ : per switching period. For a MOSFET, the behavior in conduction regime is similar to that of a resistor, the powers dissipated during this phase and during the switching phases are defined according to [4] by the following equations:

$$P_{\text{Cond}} = f \cdot W_{\text{Cond}} = \frac{T_{\text{Cond}}}{T} \cdot V_{\text{on}} \cdot I_{\text{in}} = \alpha \cdot I_{\text{in}}^2 \cdot R_{\text{DSon}} \quad (2)$$

$$P_{\text{Cond}} = (W_A + W_B) \cdot f = \frac{1}{2} \cdot V_{\text{in}} \cdot I_{\text{in}} (t_{\text{com}} + t_{\text{Bloc}}) f + \frac{1}{2} \cdot V_{\text{in}} \cdot I_{\text{RM}} \cdot f \cdot t_{\text{com}} \quad (3)$$

With :  $W_A$ : Energy dissipated during the firing phase,  $W_B$ : Energy dissipated during the blocking phase,  $W_{\text{Cond}}$ : Energy dissipated during the conduction phase,  $W_T$ : Total energy dissipated by the MOSFET,  $R_{\text{DSon}}$ : Source drain resistance of the MOSFET,  $V_{\text{in}}$ : Voltage at the terminals of the transistor in the blocked state,  $I_{\text{in}}$ : current delivered by the generator,  $I_{\text{RM}}$ : amplitude of the diode's overlay current,  $\alpha$ : the duty cycle,  $f$ : the switching frequency of the MOSFET,  $t_{\text{com}}$ : duration of the switching phase, and  $t_{\text{Bloc}}$ : duration of the blocking phase.

In summary, the total losses at the MOSFET can be evaluated by:

$$P = f \cdot W_T = \alpha \cdot I_{\text{in}}^2 \cdot R_{\text{DSon}} + \frac{1}{2} \cdot V_{\text{in}} \cdot I_{\text{in}} (t_{\text{com}} + t_{\text{Bloc}}) f + \frac{1}{2} \cdot V_{\text{in}} \cdot I_{\text{RM}} \cdot f \cdot t_{\text{com}} \quad (4)$$

## Losses in the diode

When the diode is blocked, it behaves like a perfect capacitor because there is virtually no current flowing through it and only the voltage across it varies. When it is on, the voltage and the current vary. The other losses of the diode have been taken into account in the switching losses of the MOSFET, only the conduction losses are considered here. These are in the form of:

$$P_F = V_d \cdot I_{out} \text{ with } V_d = R_d \cdot I_{in} + V_F \quad (5)$$

$$P_F = (1 - \alpha) [R_d \cdot I_{in}^2 + I_{in} \cdot V_F] \quad (6)$$

with  $R_d$  : differential resistance or dynamic resistance et  $V_F$  : direct voltage.

## Losses in the capacitor

In most cases, a capacitor is a simple capacitance  $C$  expressed in Farad but as a component the capacitor is not limited to its simple capacity:

$$P_{Cap} = R_C \cdot I_{RMS}^2 \quad (7)$$

We can rewrite (7) thanks to the expressions of the effective currents in the various components of the circuit developed in [5] in the form:

$$P_{capacitor} = R_C \alpha (1 - \alpha) I_{in}^2 + \frac{R_C}{12} (1 - \alpha) \left( \frac{\alpha \cdot V_{in}}{L \cdot f} \right)^2 \quad (8)$$

## Losses in the inductor

The equivalent electrical model of a wound inductor can be reduced to an ideal inductor in series with a resistor  $R_L$ . The presence of the latter generates direct losses by Joule effect linked to the conductors and to the losses induced in the magnetic core (losses by hysteresis and by eddy currents) which depend on the frequency and the variation of the flux.

$$P_{Inductor} = R_L \cdot I_{L,RMS}^2 \quad (9)$$

$$P_{Inductor} = R_L I_{in}^2 + \frac{R_L}{12} \left( \frac{\alpha \cdot V_{in}}{f \cdot L} \right)^2 \quad (10)$$

The expressions (11) and (12) of the average voltage of the inductance and the average current of the capacitor of a boost converter, make it possible to establish a relation showing the influence of the losses generated by  $R_L$  of the inductance on the output of this converter according to the electric quantities of the circuit [6].

$$\langle V_L \rangle = 0 = V_{in} - R_L I_{in} - (1 - \alpha) \cdot V \quad (11)$$

$$\langle i_C \rangle = 0 = (1 - \alpha) \cdot I_{in} - \frac{V}{R} \quad (12)$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{1}{1 + \frac{R_L}{R \cdot \alpha^2}} \quad (13)$$

For application, we used a MOSFET type IRFZ44E [7], a Standard silicon rectifier diodes 1N 5059...1N 5062 [8], a capacitor APSA100ESS680MFA5S [9] and an inductor muRata|Ps 49101sc [10].

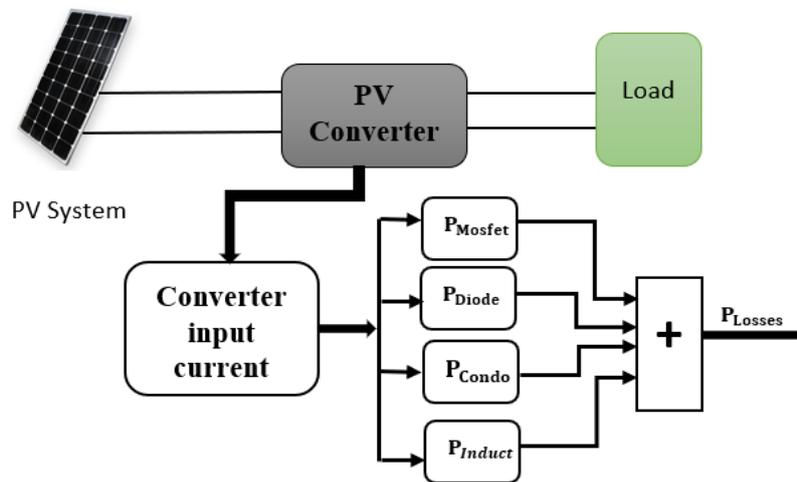
Using the datasheets of all these components, the equations for calculating the losses as a function of the current through them are summarized in Table 1.

**Table 1:** Loss evaluation equations

Parameters	Equations
$P_{Mofset}$	$(8.625e^{-3})I_{in}^2 + (0.234)I_{in} + 34.53e^{-3}$
$P_{Diode}$	$(2.562e^{-2})I_{in}^2 + 0.688I_{in}$
$P_{Capacitor}$	$(5.86e^{-3})I_{in}^2 + 0.0732$
$P_{Inductor}$	$(0.165)I_{in}^2 + 0.938$

## Loss calculation method

From the equations listed in Table 1, the block model in Figure 2 has been developed in Simulink to calculate the losses generated by a single-inverter PV system. Each of its blocks modeling the losses whose sum represents the total loss of the converter receives at its input the current  $I_{in}$  which is the equivalence of the current  $I_{PV}$ . This calculation block is associated with the MPPT control system that is implemented in the converter.



**Figure 2:** Total loss calculation blocks of a DC-DC converter in a PV system.

## Results and discussions

We have evaluated the losses in the components including the switching cells (MOSFET, diode) and passive components of a DC-DC converter. On figure 3 showing the characteristic curves of the losses generated by these components as a function of the global current, we can notice that the losses in the capacitor, the MOSFET and in the diode are almost linear while the losses in the inductor evolve exponentially with the global current. In terms of efficiency, a cross analysis between figure 3 and 4 shows that the influence of these losses on the conversion efficiency is directly proportional to the losses generated by each component of the converter.

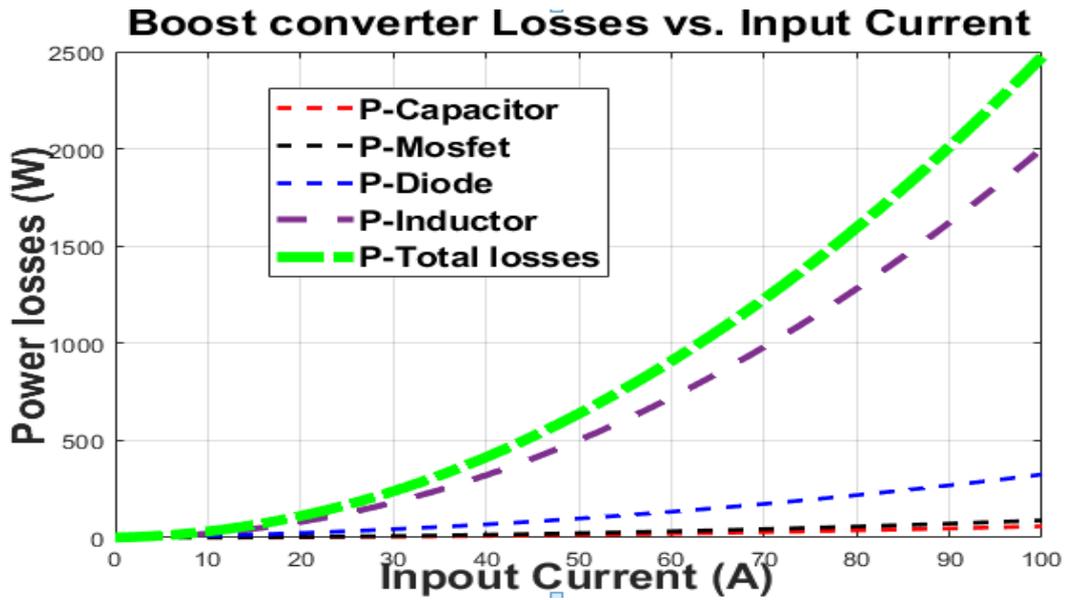


Figure 3: Changes in losses based on global current

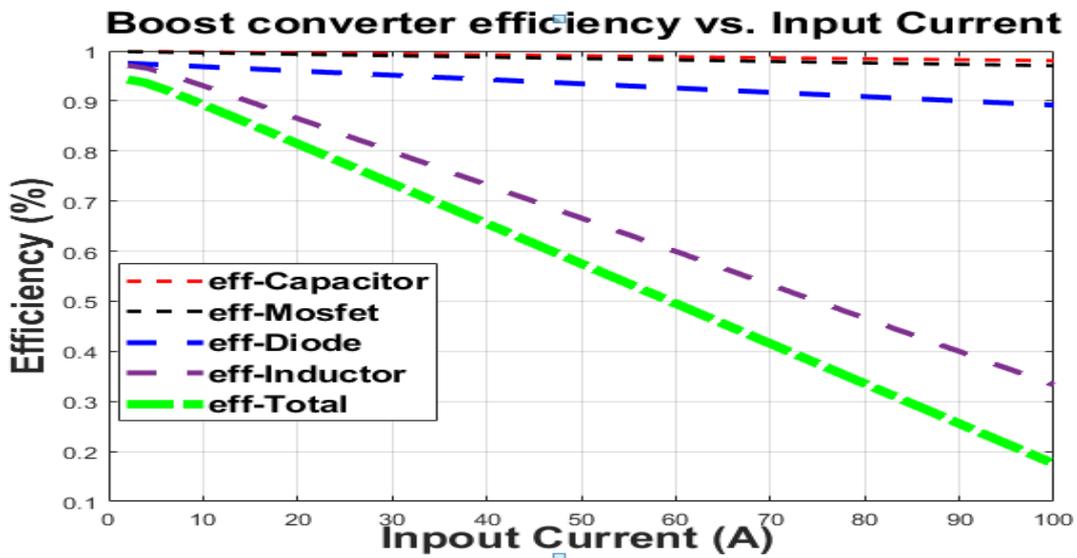
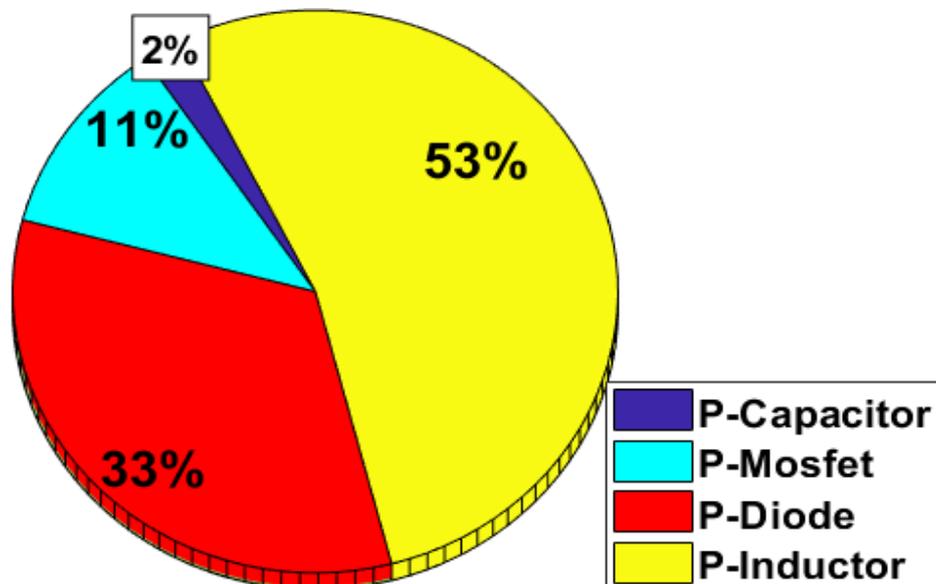
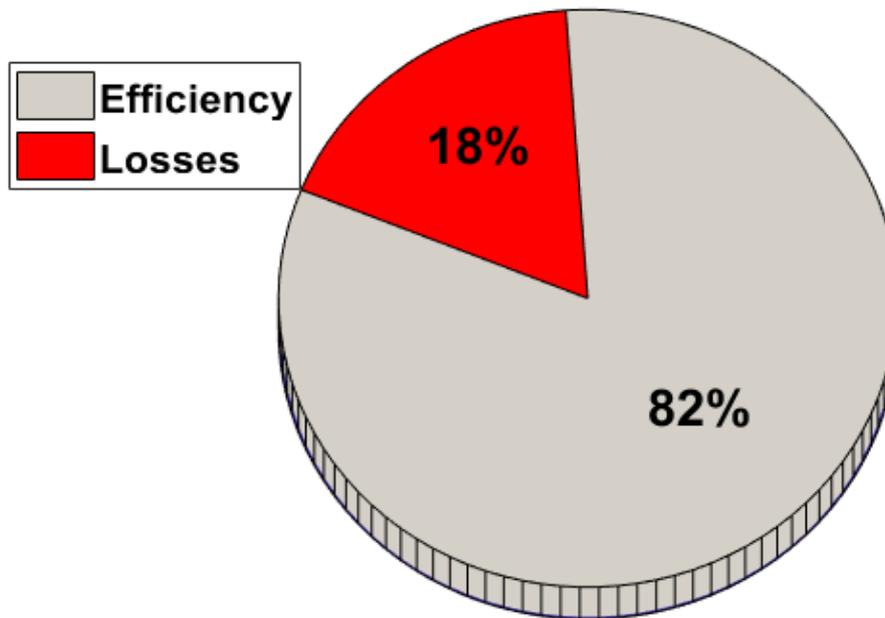


Figure 4: Influence of losses on efficiency



**Figure 5:** Loss distribution diagram**Figure 6:** Total loss diagram.

Then, the simulation is performed under MATLAB / Simulink with a 240 KW PV generator and a purely resistive charge of  $9.6 \Omega$ . By applying the Figure 1 loss calculation block, Figure 6 shows that for a 240W PV source, a converter can encroach on conversion output up to 18% of the total power available at its in, reducing conversion power to 82%. Figure 5 shows that 53% of its losses are caused by the inductor, 33% by the diode, 11% by the MOSFET and only 2% by the capacitor.

## Conclusion

The total efficiency of the converter is strongly influenced by the efficiency of the induction since the efficiency of the capacitor and MOSFET always remain above 95% and 90% respectively. While the efficiency of the diode which is 67% is still acceptable, the induction seems to impose its losses on the converter we simulated. Thus, in order to boost the efficiency of the converter, we must try to work a lot on the effectiveness of the inductor.

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