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Performance Analysis of the Multi-Level Boost Converter (MLBC) connected in a Photovoltaic System

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Abstract

The paper concentrates on a comparison between two DC/DC converters topologies, the conventional Boost and the Multi Level Boost Converter (MLBC), for connecting into PV systems. Several performance criteria are included as part of this comparison process for both converters under varying climatic conditions (irradiation and/or temperature). The DC/DC converters' function is to serve as an interface between PV generator and load. We apply MPPT (Maximum Power Point Tracking) control with α duty cycle adjustment using PWM technique for extracting the highest achievable output power from PV generator. The multilevel boost converter (MLBC), which is capable of monitoring and maintaining an equal voltage on all N output levels, along with controlling the input current. MATLAB/Simulink simulation results highlight the performance of the Multi-Level Boost Converter (MLBC) converter topology, to match the GPV voltage to the load.

Keywords: PV, MPPT, DC/DC Converter, Boost, MLBC, Comparison

1. Introduction

During last years, solar energy has known a significant use and integration in whole of the world, which is caused to the free energy and its use in standalone system or integration to power grids becomes easy [1,2]. Photovoltaic panels generate low voltages which can't meet the requested voltage by the load with the variation of irradiance [3]. So, the output voltage needs to be regularized using special system [4]. DC/DC converters are installed to satisfy this need and to be adapted to application exigences [5]. To obtain high duty cycle to increase output voltage, many topologies of DC/DC converters exist and adapted to boost techniques [6]. Boost traditional converter is not preferred practically to achieve the potential adaptation with the required one by the load, and this is due its conception constraints, its low efficiency, …etc. [7]. many topologies are presented such as switched inductor DC/DC boost converter (SI) [8], multilevel boost converters (MLBC) [9],[3], The single-ended primary-inductance converter (SPEIC) [10] …etc. The multilevel boost converters are recommended too for photovoltaic DC links [5].

Our present paper provides a detailed comparison between traditional boost converter and multilevel boost one. Our innovation consists to highlight the multilevel converter advantages and its performance with a real irradiance profile. The work is structured as follows: The complete model containing solar panel, DC/DC converter and load is described in section II. Section III presents a comparison of the traditional boost and multilevel boost converters. The obtained results with a constant and variable irradiance profiles are presented and discussed in section IV. Finally, the main remarks and recommendations are given in the conclusion.

2. Description of model

The photovoltaic array supplies the load through the following two DC/DC converters' topologies: Traditional and multilevel boosts (MLBC). The used MPPT control technique is incremental conductance (IncCond), with the aim of delivering maximum output power into the load (as illustrated in Fig 1).

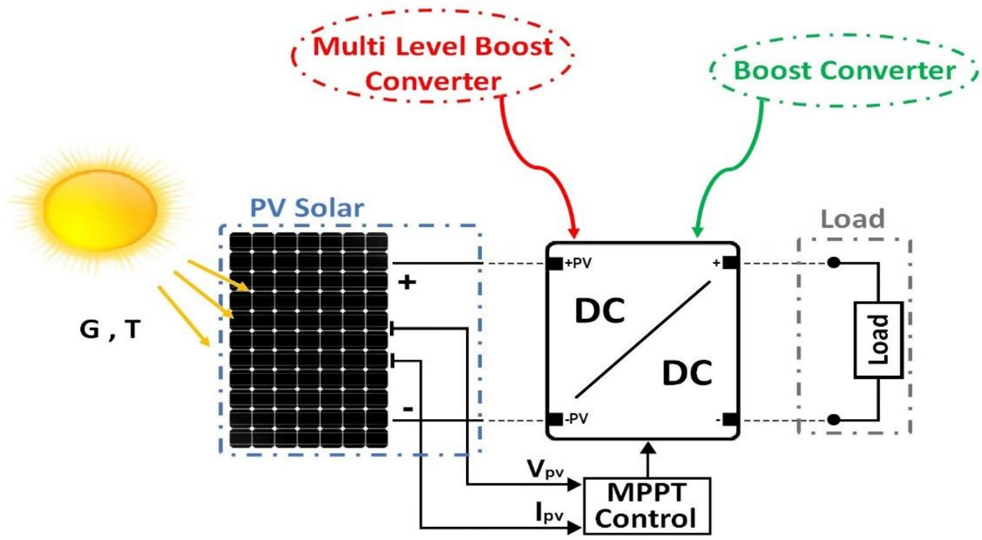


Fig 1. Studied system

The output current of the PV panel is given by [2]:

$$I = I_{ph} - I_s \times \left[\exp\left(\frac{q\times(V+R_s\times I)}{A\times K\times T_c}\right) - 1\right] - \left(\frac{V+R_s\times I}{R_P}\right) \quad (1)$$

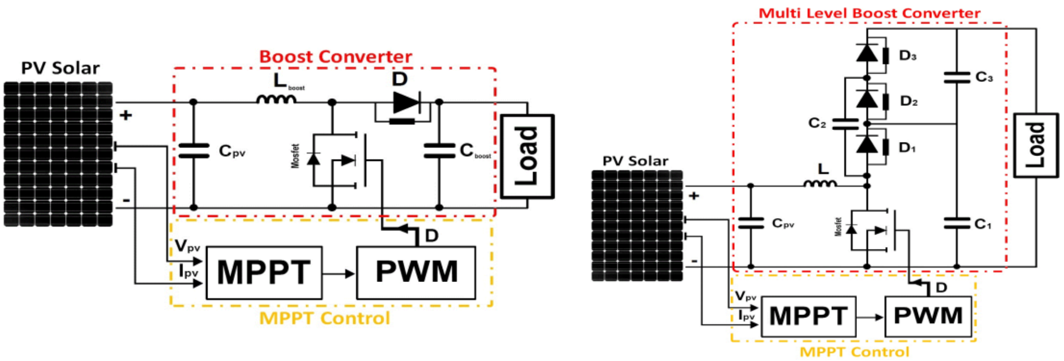
We used a model solar generator (SPR-305E-WHT-D) of power 305 Watt in STC, and an irradiation of one day of Summer Season. The Table 1 illustrates the parameters of the system.

Table 1. System Simulation Settings

	Parameter	Value
PV Panel (SPR-315E-WHT-D)	PV power at 1000 W/m²	305 W
	GPV power at 1000 W/m² (2×1)	610 W
	Voltage at maximum power (V_{mpp})	54.7 V
	Current at maximum power (I_{mpp})	5.58 A
	Open circuit voltage	64.2 V
	Short circuit current	5.95 A
	Number of cells	96 cells
Boost Converter and Multi-Level Boost Converter	Input capacitor (C_{pv})	2.5 mF
	Inductor (L_{Boost}, L_{MLBoos})	250 μH
	Capacitor (C_{Boost})	1 mF
	Capacitor (C_1, C_2, C_3)	1 mF
	Working frequency	15 kHz

3. Control of DC/DC Converters

The photovoltaic conversion chain contains a DC/DC power converter. These converters allow the input voltage of a system to be adjusted to the desired output voltage. There are several types of DC/DC converter topologies that have been discussed in the literature for photovoltaic applications [11]. In this work used two topologies' converters: the traditional boost and multilevel boost converters respectively (Fig 2):



(a) (b)

Fig 2. DC/DC converters for PV stand-alone application (a) Traditional boost converter (b) Multilevel boost converter (MLBC) [3]

3.1 Boost converter

Traditional boost converter is a basic model and it is still the platform that rely on it to create other topologies, The transformation ratio of the converter is controlled by a PWM signal with two modes of function (Mosfet opened or closed) [11,12]. Fig 2(a) is shown boost converter it is characterized by its simple structure.

The following expressions give the relationship between the output and the input of voltages and currents :

$$V_0(1-\alpha) = V_i \quad \Rightarrow \qquad V_0 = \frac{V_i}{(1-\alpha)} \tag{2}$$

$$I_o = (1-\alpha)I_L - C_o\frac{dV_o}{dt} \tag{3}$$

With:

$\alpha = \frac{T_{on}}{T}$: Duty cycle between 0 and 1

I_L : Inductance current ; I_c : Capaciter current ; I_o : Output current ; V_i : Input voltage.

3.2 Multi Level Boost Converter (MLBC)

Multilevel boost converter (MLBC) topology for MPPT is illustrated in Fig 2(b) [9], [3], the output voltage of the converter is proportional to the number of levels Ni (i=1,2, 3...), which can be increased by adding two additional capacitors and diodes [9]. Fig. 3 illustrates the graphical analysis of the converter when the switch is "on" and "off", two levels MLBC is used in this work.

$$Ni * \frac{1+\alpha}{1-\alpha}\ V_i \tag{4}$$

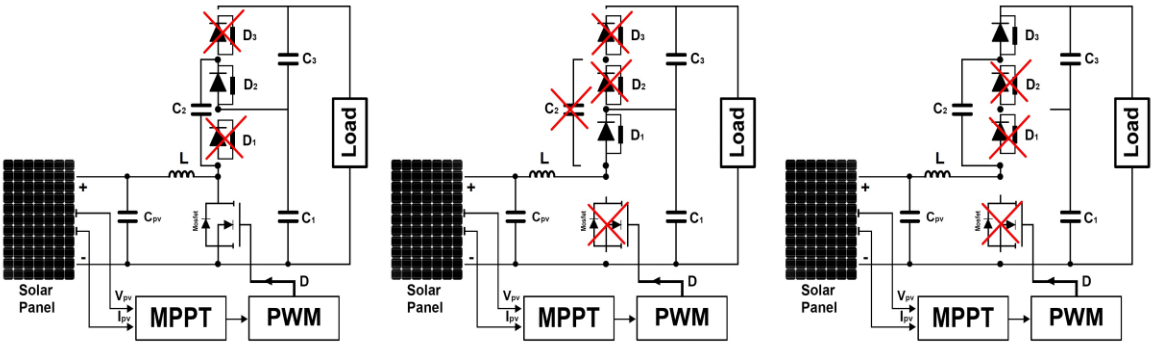
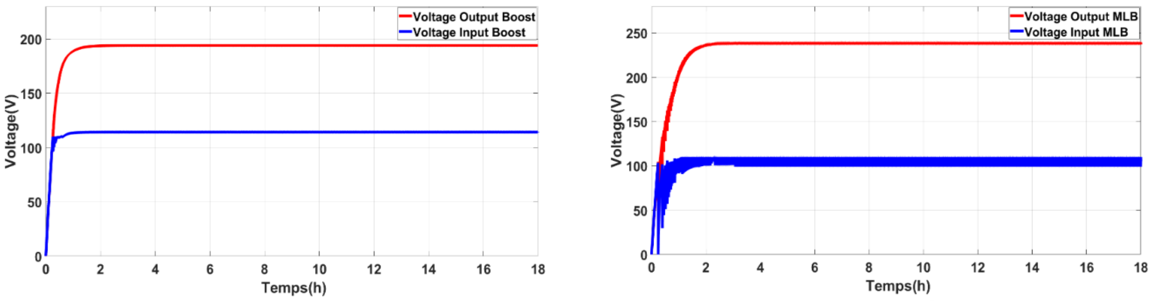


Fig 3. Multi-level Boost Converter (a) Switch is ON (b) Switch is OFF (D_1) (c) Switch is OFF (C_2, D_3) [9]

4. Results and discussion

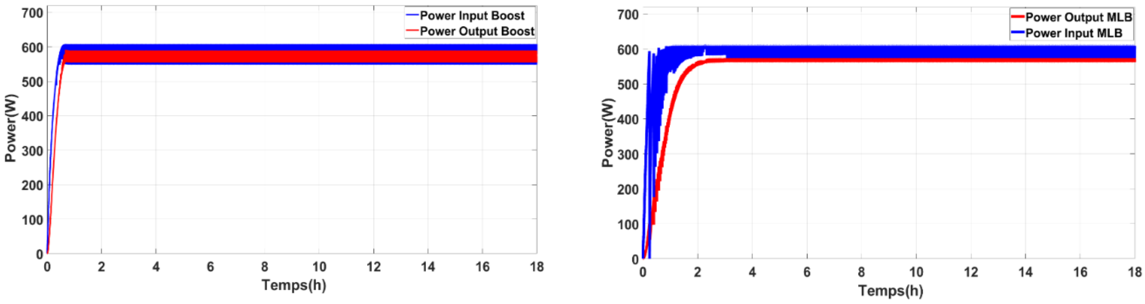
Our model has been simulated using MATLAB environment. It consists of two panels which are SPR-305E-WHT-D module type (already detailed in the second section). Two different cases have been simulated: in the first one the irradiance has been considered constant with STC. The obtained consisting in input and output boost voltages are shown in Fig 4(a) for traditional boost converter and Fig 4(b) for multilevel boost one. The input and output boost converter powers are shown for traditional boost and multilevel one in Fig 5(a) and Fig 5(b) respectively. The multilevel boost capacitors instantaneous voltages are shown in Fig 6. The second simulation has used a summer day irradiance profile (Fig 7). The obtained input and output voltages, powers and multilevel boost capacitors voltages are presented in the Fig 8, Fig 9 and Fig 10 respectively.

4.1 Irradiance constant (G= 1000 W/m², T=25°C)



(a) (b)

Fig 4. Output voltage (a) Traditional boost converter (b) Multi-Level boost converter



(a) (b)

Fig 5. Output power (a) Traditional boost converter (b) Multi-Level boost converter

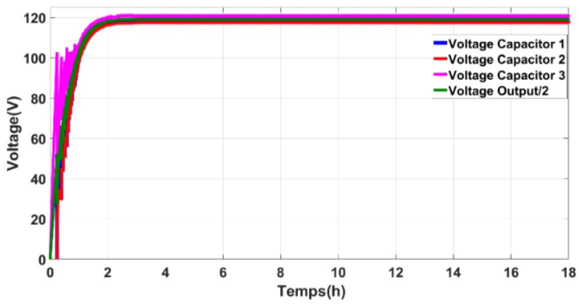


Fig 6. Voltage capacitors

4.2 Irradiance summer season day

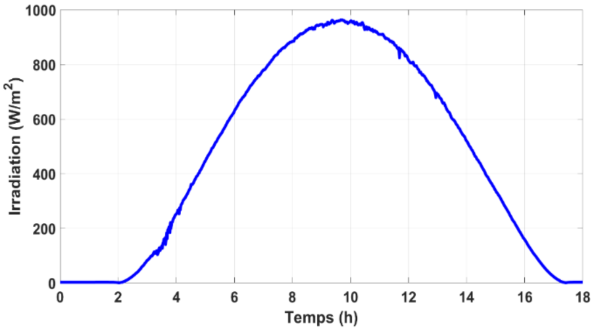


Fig 7. Irradiance summer season day

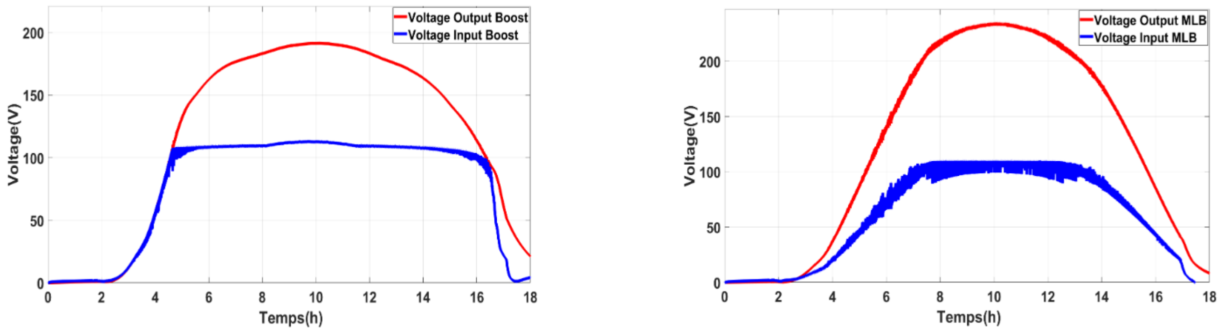


Fig 8. Output voltage (a) Traditional boost converter (b) Multi-Level boost converter

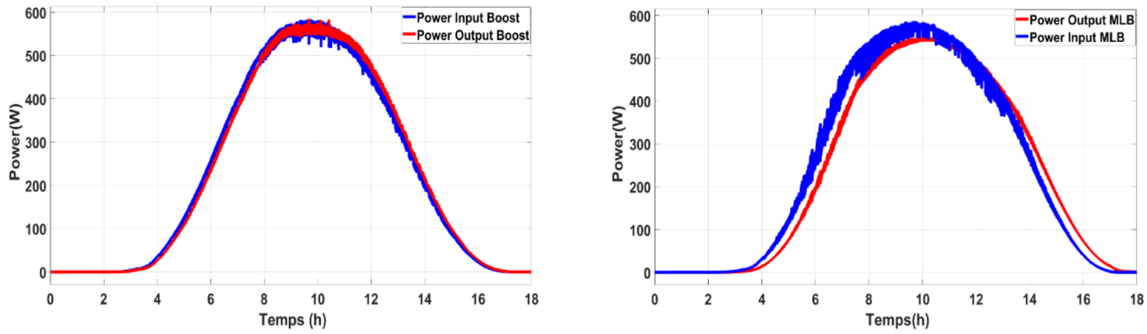


Fig 9. Output power (a) Traditional boost converter (b) Multi-Level boost converter

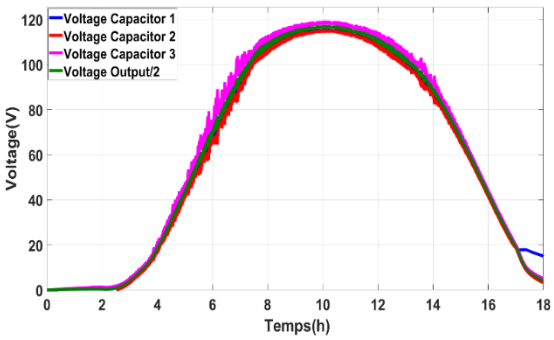


Fig 10. Voltage capacitors

From Fig 4(a) and Fig 4(b) the multilevel boost converters gives higher output voltage with the same applied constant irradiance, and a slight increase of the output power (Fig 5(a) and Fig 5(b)) and this is caused to duty cycle α and the number of levels $[V_{out} = nV_c = N * \frac{1+\alpha}{1-\alpha} V_{in}]$ where the voltage has been equitably divided on the multilevel capacitors (Fig 6) and the output voltage is the sum of all the capacitor voltages. The reduced output voltage obtained with traditional boost converter is due to its dependence with duty cycle α only $[V_{out} = \frac{V_{in}}{1-\alpha}]$.

When comparing the boost converters behavior under variable irradiance, the multilevel converter gives higher output voltage and power (Fig 8 and Fig 9) and the potential has been divided on all the capacitors equitably (Fig 10). We note that the output voltage response with slow irradiance variation is much better using multilevel boost converter.

5. Conclusion

Our paper has presented a comparative study and simulation of solar PV panel connected to two different DC-DC Boost converters: traditional boost converter and multilevel one. The converters have used IncCond control for standalone system. The converters have been simulated when connected to solar panel exposed to constant irradiance and variable one. For both irradiance cases, the multilevel boost configuration has given a greater output voltage and power comparing to the traditional one. This is due to the multilevel boost configuration which include several voltages levels where the potential has been equitably divided on the capacitors. On the other hand, multilevel boost converter has given best response with slow irradiance variation during the day. In conclusion, the performance of multilevel boost converter is proved in terms of efficiency, dynamic range and low ripple.

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