Performance Enhancement of Quadratic Boost Converter over Boost Converter under Varying Solar Irradiance Conditions

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Abstract. The demand for efficient DC-DC converters capable of providing significant voltage step-up with minimal losses is critical in numerous applications, such as portable devices, electric automobiles and energy-efficient systems. Among the various boost converter topologies, the Boost Converter is widely used for moderate voltage gains but becomes less efficient at high voltage step-ups due to the challenges of handling large duty cycles. In contrast, the Quadratic Boost Converter offers a superior solution for high voltage gains, providing better efficiency by utilizing a cascaded two-stage boosting mechanism, which allows for lower duty cycles and reduced switching losses. This study provides a comparison of the Boost Converter with the QB Converter with different duty ratios, different solar irradiances and emphasizing the latter's advantages regarding efficiency, gain in voltage and suitability for high-performance applications. Through simulations, and efficiency comparison, we demonstrate that the Quadratic Boost Converter not only achieves higher voltage gains but also operates more efficiently at elevated step-up ratios, making it more preferable in systems where efficiency is critical. This analysis establishes the Quadratic Boost Converter as a more favorable choice for modern power conversion systems demanding high voltage gain with optimal efficiency.

Keywords: Boost Converter, Quadratic Boost Converter, irradiance, duty ratio, efficiency and output voltage.

1 Introduction

In recent times, the demand for effective voltage step- up transformers has surged across a variety of operations, encompassing energy from renewable sources (similar as photovoltaic power transformers), electric vehicles, and movable electronic bias. DC to DC transformers play critical part within such structures, where the thing is to convert a lower input voltage to a advanced affair voltage with minimum loss. Among the colorful types Boost Converter, a DC-DC transformer is generally used topologies

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due to its ease of use and capability to increase voltage by conforming a switch's duty cycle. still, while Boost Adaptor is effective for moderate voltage earnings, its performance deteriorates at high voltage step- ups, as it requires high duty cycles that lead to increased switching losses, reduced effectiveness, and complex control conditions. To address these challenges, the Quadratic Boost Converter has surfaced as a promising volition, especially for operations that bear high voltage earnings. The Quadratic Boost Converter operates by using two cascaded stages of boosting, offering a quadratic relationship between the input and affair voltages. This configuration allows for significantly advanced voltage earnings at lower duty cycles compared to the traditional Boost Converter, thereby reducing switching losses and perfecting overall effectiveness. While the Quadratic Boost Converter introduces added complexity in terms of design and control, its advantages in effectiveness and voltage gain make it decreasingly preferable for high- performance operations. This paper presents a relative analysis of the Boost and the Quadratic Boost Converters with the end of demonstrating the ultimate's superiority in high- voltage step- up operations. We examine crucial performance criteria similar as voltage gain, effectiveness, and control complexity, pressing the benefits of the Quadratic Boost Converter in scripts where high voltage earnings are demanded without immolating effectiveness. Through both theoretical analysis and simulation results, we show that the Quadratic Boost Converter, despite its further intricate design, provides a more effective and scalable result for ultramodern power conversion systems, making it the favored choice for high power operations.

2 Methodology

The comparison between the Boost and the Quadratic Boost(QB) Converters is executed through both results of simulations and theoretical study under a range of operating conditions. The following steps outline the methodology used to perform this comparison. To establish a baseline for comparison, the theoretical principles behind each converter are first outlined.

2.1 Boost converter

The Boost Converter's objective is to raise the voltage input to the level of the intended output voltage. Numerous DC sources, including rectifiers, solar panels, batteries, and others, can supply the input to this converter. Figure 1 depicts the Boost Converter's circuit diagram.

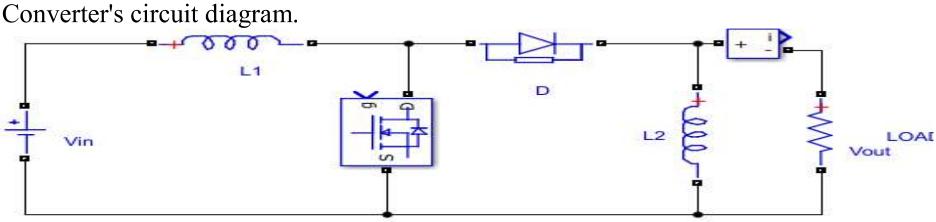

Fig.1. Boost converter model

With an emphasis on its voltage gain equation, the Boost Converter's working principles are based on switch turn-on and turn-off procedures. The connection among the current with voltage of L (inductor) is

$$\mathrm{i} = \frac{1}{\mathrm{L}}\int_0^{\mathrm{t}} \mathrm{Vdt} + \mathrm{i_o} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\mathrm{V} = \mathrm{L}\frac{\mathrm{di}}{\mathrm{dt}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The current can be stated as follows once that switch turned on:

$$\Delta \mathrm{i} = \frac{(\mathrm{V_{in}} - \mathrm{V_{trans}})\mathrm{T_{on}}}{\mathrm{L}} \ldots\ldots (3)$$

The following is an expression for the current while a switch is off:

$$\Delta \mathrm{i} = \frac{(\mathrm{V_{outb}} - \mathrm{V_{inb}} + \mathrm{V_D})\mathrm{T_{off}}}{\mathrm{L}} \ldots\ldots (4)$$

The Vout can be solved by equating the aforementioned equations.

$$\mathrm{V_{outb}} = \frac{\mathrm{V_{inp}} - \mathrm{V_{Tran}}\mathrm{K}}{1 - \mathrm{K}} - \mathrm{V_D} \ldots\ldots (5)$$

Ignoring losses in voltages across VTrans and V_D

$$\mathrm{V_{outb}} = \frac{\mathrm{V_{inp}}}{1 - \mathrm{K}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

2.2 Converter of QB(Quadratic Boost)

A converter of QB (Quadratic Boost) can effectively raise the DC voltage from a photovoltaic (PV) array [2], [4], ensuring a constant and high voltage level for subsequent power conversion stages of direct usage in DC applications. This method can be very helpful for applications that require high step-up voltage gains from a low-voltage PV array. By alternating the switch between it's ON and OFF states, the resulting equation for the proposed converter of QB (quadratic boost) can obtained.

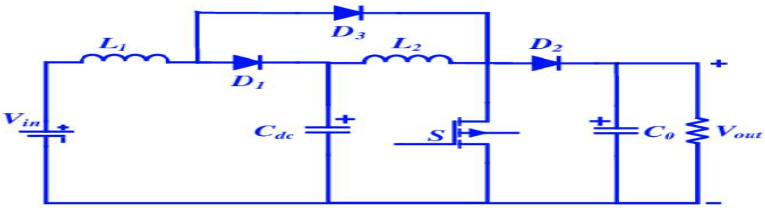

Fig.2. converter model of QB

The moment a switch is activated, Figure 2 illustrates how the currents in the QB converter's inductors rise, and they can be expressed by

$$(\Delta I_{L1})On = \frac{VsKT}{L1} \ldots\ldots\ldots\ldots\ldots\ldots..(7)$$

$$(\Delta I_{L2})On = \frac{Vc1KT}{L2} \ldots\ldots\ldots\ldots\ldots\ldots..(8)$$

As the switch is turned off Figure 2 illustrates how the currents in the QB converter's inductors drop, and they can be expressed by

$$(\Delta I_{L1})Off = \frac{(V_s - V_{c1})(1-K)T}{L1} \ldots\ldots\ldots\ldots.(9)$$

$$(\Delta I_{L2})Off = \frac{(V_{c1} - V_o)(1-K)T}{L2} \ldots\ldots\ldots\ldots.(10)$$

A converter of QB's resultant voltage (Voutq) can be described as proceeds by resolving the aforementioned equations for the turn ON and OFF modes:

$$Voutq = \frac{Vs}{(1-K)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

3 Simulation results and Discussion

3.1 Simulation results of the converter of Boost

Model of converter with Boost is simulated, and Fig. 3 displays the circuit. The circuit operates at 1 kHz with an irradiance of 1000w/m^2. The switches are ideal in theory hence the circuit has no losses. However, switches in modeling circuits are not optimal therefore output voltage losses will occur.

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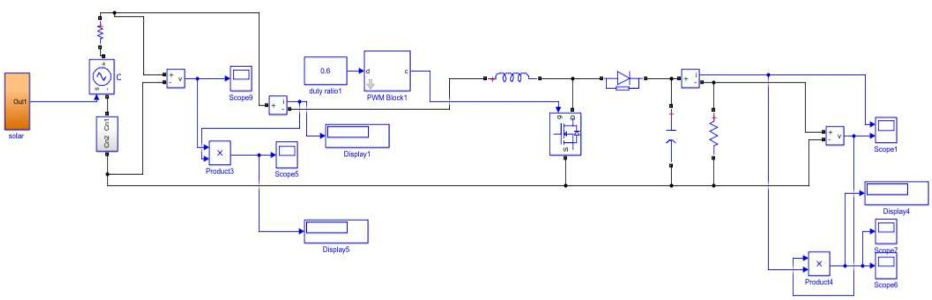

Fig.3. Simulation model of Converter of Boost

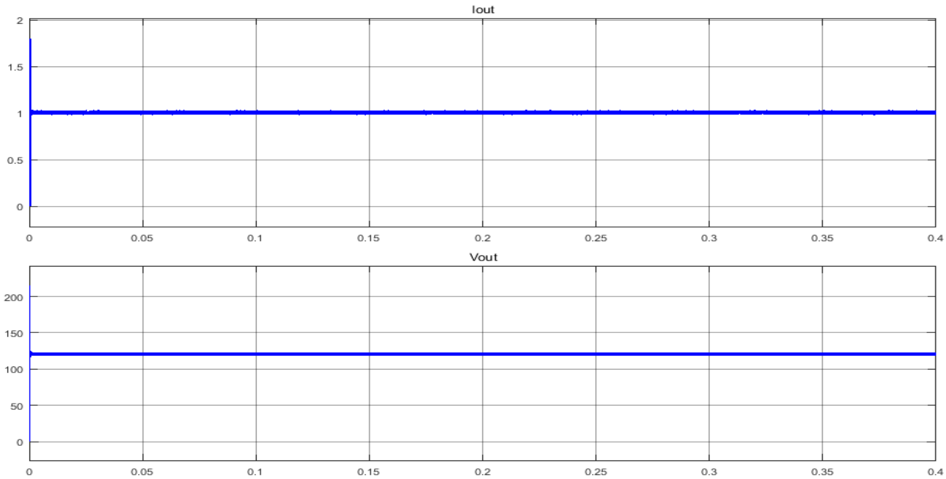

Fig.4. converter of Boost's Vout and Iout at the irradiance of 1000 w/m^2

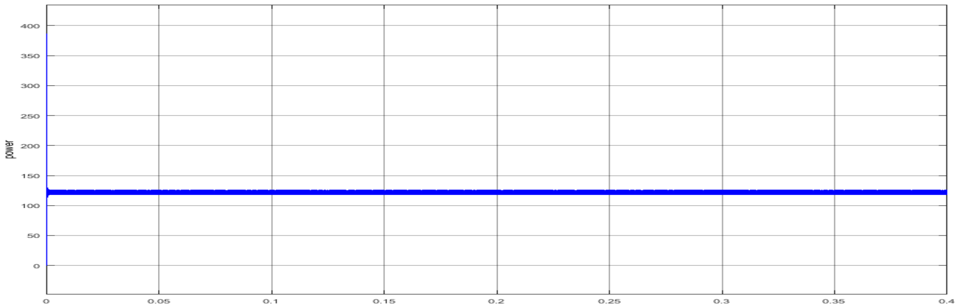

Fig .5. Converter of Boost Pout at irradiance of 1000 w/m^2

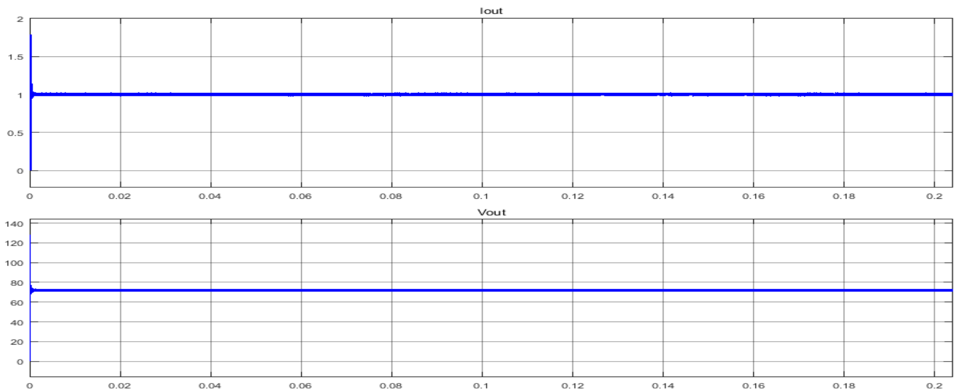

Fig.6. Converter of Boost Vout and Iout irradiance of 800 w/m^2

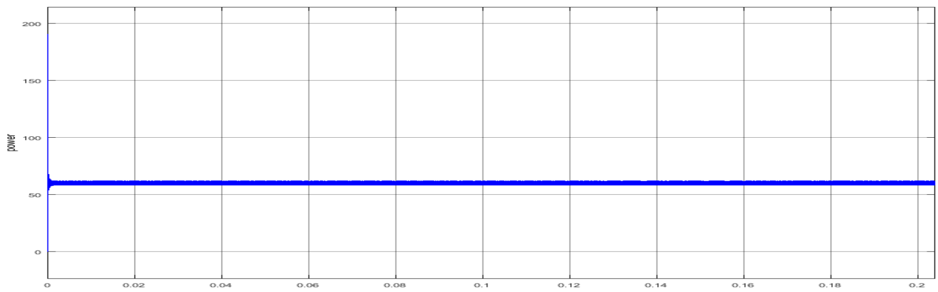

Fig.7. Converter of Boost Pout at irradiance of 800 w/m^2

The resultant voltage(Vout), current(Iout), and Power(Pout) of the converter of Boost for 1000 watts/m^2 of irradiance are clearly displayed in figure 4 and figure 5. The resultant voltage (Vout), current (Iout), and Power(Pout) of the converter of Boost for an irradiance of 800 watts/m^2 are clearly displayed in figure 6 and figure 7. Here, we can see that altering the irradiance lowers the output voltage and power. Table 2 shows the output analysis and efficiency of a boost converter with 1000 (w/m^2) of irradiance at various duty ratios.

3.2 Converter of Quadratic Boost (QB) Simulation results

Model of the converter of QB is simulated, and Fig.8 displays the circuit. The circuit operates at 1 kHz with an irradiance of 1000w/m^2. The switches are ideal in theory hence the circuit has no losses. However, switches in modeling circuits are not optimal therefore output voltage losses will occur.

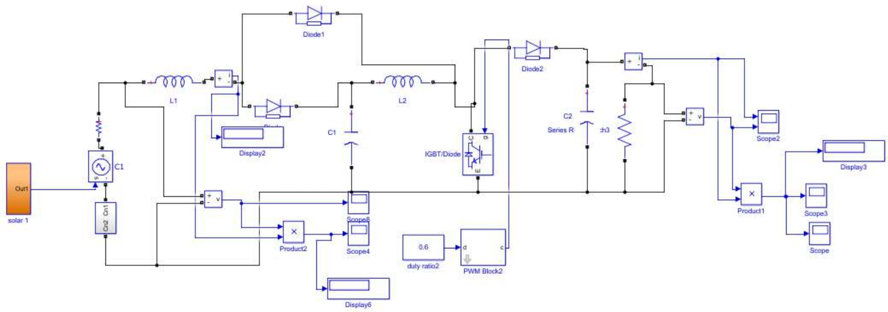

Fig. 8. Simulation model of Converter of QB

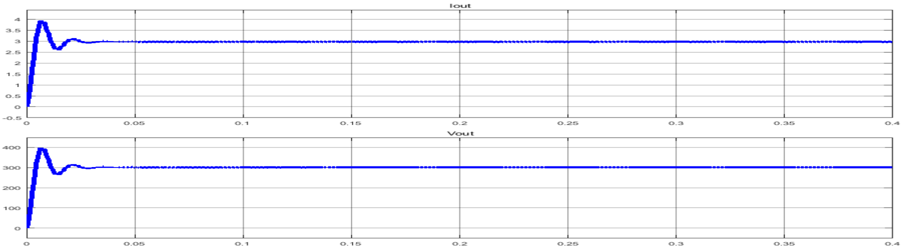

Fig. 9. Quadratic Boost converter Output Voltage and Output Current 1000 w/m^2 Irradiance

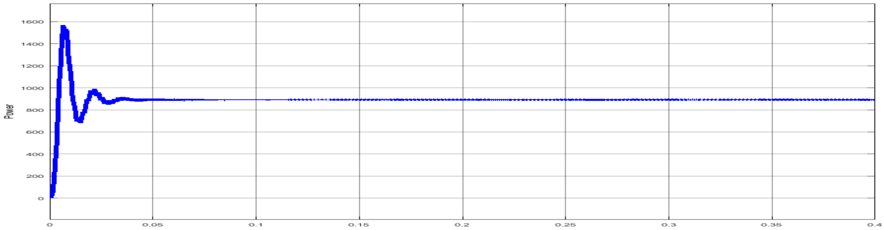

Fig. 10. Quadratic Boost converter Output Power at 1000 w/m^2 Irradiance

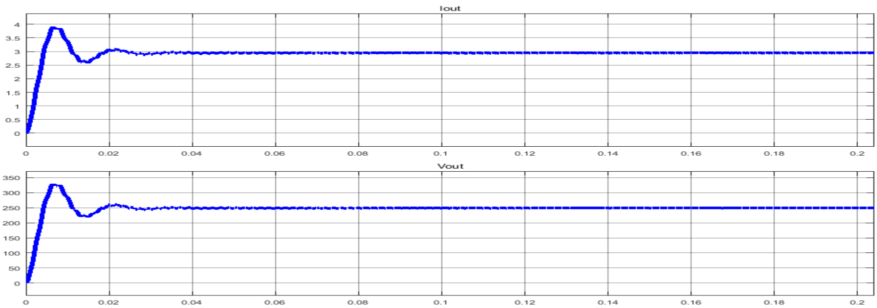

Fig. 11. Quadratic Boost converter Out put Voltage and Out put Current 800 w/m^2 Irradiance

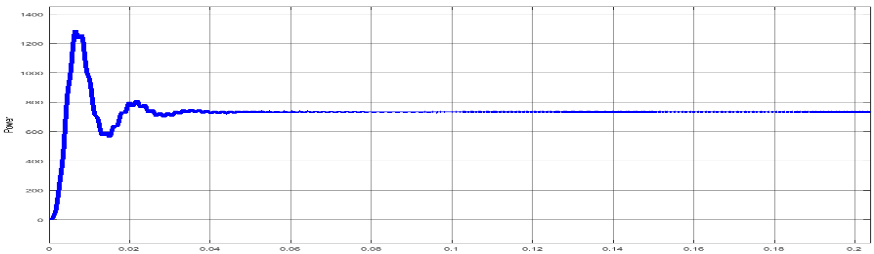

Fig. 12. Quadratic Boost converter Output Power at 800 w/m^2 Irradiance

The resultant voltage(Voutq), current(Ioutq), and Power(Poutq) of the converter of quadratic boost for 1000 watts/m^2 of irradiance are clearly displayed in figure 9 and figure 10. The resultant voltage (Voutq), current (Ioutq), and Power(Poutq) of the converter of quadratic boost for 800 watts/m^2 of irradiance are clearly displayed in figure 11 and figure12. Here, we can see that altering the irradiance results in a decline in the output voltage and power. Table 3 shows the output analysis and efficiency of a quadratic boost converter with 1000 (w/m^2) of irradiance at various duty ratios.

Table1 indicating that for same irradiance a K (duty ratio) and Voutq (output voltage) is more in Quadratic boost converter comparatively wit boost converter in high power applications.

Table 1: Resultant voltage analysis of Converters of Boost and (QB) Quadratic Boost

Model of Converter	**Irradiance(w/m^2)**	**(K)Duty ratio of converters**	**Converters Resultant voltage(V)**
Converter of Boost	1000	0.6	123.8
	800	0.6	76
Converter of Quadratic Boost (QB)	1000	0.6	299
	800	0.6	256

Table.2 Resultant Analysis of Converter of Boost with 1000(w/m^2) Irradiance with different duty ratios

(K)Duty ratio of converter	**Converters Resultant voltage(V)**	**Converters Resultant Current(A)**	**Converters Resultant Power(W)**	**% Efficiency**
0.5	96	1.2	115	63.88
0.6	123.8	1.04	127.92	64.06

Table.3 Output Analysis of Quadratic Boost Converter with 1000(w/m2) Irradiance with different duty ratios

(K)Duty ratio of converter	**Converters Resultant voltage(V)**	**Converters Resultant Current(A)**	**Converters Resultant Power(W)**	**% Efficiency**
0.5	125	1.4	173	91.05
0.6	299	2.942	879.7	91.56

4 4. Conclusion:

This research examines the performance efficiency of converters of Boost and (QB) quadratic boost leveraging simulation. The quadratic boost converter provides a clear performance advantage over the standard boost converter, especially in environments with variable or low solar irradiance. Its higher voltage gain, improved efficiency, and better response to irradiance fluctuations make it an ideal choice for solar energy systems requiring consistent power output and higher performance. However, for simpler or cost-sensitive applications, the standard boost converter may still be a viable option despite its lower efficiency under certain conditions.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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