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Mythology Study and Comparison for Quadratic DC-DC Step-up Converters

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Abstract: Electronic systems reliant on solar sources need DC voltage over 50 volts; hence, the use of converters is essential to satisfy client requirements. Converters modify the output voltage based on the input voltage. Quadratic DC-DC step-up converters are often used to enhance voltage transfer gain and efficiency. This sort of converter circumvents the issues associated with regular cascaded converters. Alongside the primary aims of its use, the researcher must address the practical aspects of the suggested approach, including duty cycle operational range, output voltage fluctuations, reduction of component consumption, cost, and complexity. This article examines and compares quadratic step-up converter topologies from recent years, highlighting researchers' endeavours to attain high voltage transfer gain, regulated output, and efficiency. The comparison results of the high-gain converter are shown (Table 1) to assist in selecting an appropriate high-gain topology for a particular application. Cross-references should be used there.

Keywords: Quadratic boost, Quadratic step-up, Quadratic boost topologies, Boost converter, QBC comparison.

1 Introduction

RENEWABLE energy and fossil energy are two main types of energy in nature. The depletion of fossil fuels and its high prices encouraged the developing countries to utilize the renewable energy resources in generating electricity which ensures many of the daily need. Many types of the renewable energy resources have been modified. Among these types, the photovoltaic- (PV) system is widely used since the solar energy is free and available in most countries. Nowadays, remaining underneath security voltage is very important. Also, the range of the photovoltaic panel output voltage is between 24.0 and 48.0 volts [1]. These amounts of voltage values are not enough as compared to the required value on the other side of the system. Therefore, it is necessary to use converters. The power condition DC-DC converter is required to achieve this matching between the load and the PV panels that yields the extraction of the maximum power (MP) from sun at a given radiation [2]. A converter is linked to a software environment to implement the MPPT control mechanism that aligns the specified PV panels with the load [3].The task of a MPPT in photovoltaic power system is to continuously tune the system so that it draws MP from the PV array [1]. The usage of converter increases the cost and effects on the system efficiency. Also, many authors are trying to achieve high transfer ratio which is achieved for duty cycle values close to unity and that occurs where the efficiency is lower. To increase the efficiency and voltage transfer gain (VTG), several high step-up converter topologies have been proposed by many authors. Normally several cascaded boost converters are used to meet the optimum output requirements in terms of high output voltage and increased efficiency at the last station of the cascaded DC-DC converter [4- 6]. The use of cascaded converters presents challenges due to the required amount of electronic power switches and their control, which necessitates circumventing implementation barriers, ultimately leading to increased costs [7]. Therefore, a high gain DC-DC converter is used to match the demand of high output power photovoltaic system with higher

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voltage transfer gain and efficiency. This type of intermediate stage converters suitable to meet demined of maximum voltage of direct current home, green vehicle, etc. usually the traditional converters achieved voltage high gain at the expense of a decrease in efficiency [8-9]. In conjunction with the use of a high DC-DC converter, there is a need for an output characterised by minimal oscillation, reduced conduction losses, a duty cycle range distant from unity, and a drop in component count and implementation complexity to achieve the user's optimal system output. In addition to the above, one of the most important goals that researchers seek to achieve is to reduce stress across switching devices. For reducing the stresses on the switching devices authors discussed topologies of maximum gain converters depended on using these switching devices [10-12]. This design of a DC-DC boost converter is characterised by minimal stress on the semiconductor switches. When the switch is in the ON state, energy is stored in the inductor while the capacitor discharges. The capacitor is charged in the off state, receiving energy from the inductor and the load, contingent upon the input voltage. Consequently, it ensures effective voltage control under open loop conditions.

2 Study objectives

Researchers' efforts have increased in recent years to design a quadratic step-up Converter (QSUC) to face the user's requirements for ideal performance and good cost. Authors presented different controlling techniques to improve converter's performance included voltage transfer gain range ($\boldsymbol{V_O/V_{PV}}$), output oscillation, cost, and efficiency. This research presented a comprehensive study on these converters of the recent years. A comparison is made in the performance axis of the converter, offering a method to ascertain the scope of future research in this domain. It facilitated future researchers in circumventing some challenges and striving to enhance the design.

3 Comparison study

This topic discusses the latest challenges in designing a quadrature voltage converter in terms of maximum voltage transfer gain (VTG) which is a key index for determining converter performance which includes: duty cycle range (DR), maximum efficiency ($\boldsymbol{\zeta_{Max}}$), oscillation outputs, complexity, cost represented by number of components used. Table 1 includes a scientific summary of high-voltage converters, which is distinguished by several points. So, from the table 1, it can be shown that topologies can be differentiated based on influential action points in evaluating the transformer such as voltage gain, component number, duty-cycle range, and this leads to a cost and complexity evaluation of the system. It should be noted that desirable characteristics such as duty cycle range with a low number of components are not necessarily available in all topologies. There is always a balance between high gain and number of components. Step-up (SU) converter is commonly used for high step applications due to its simple design and low cost. Conversely, its utilisation by such applications is hindered by the poor voltage transfer gain.

A modified SU converter using number of switched inductors and capacitors with one/two semiconductor switch is proposed to perform cascade converter in Quadratic SU Converter form. The research in [21,23, and 30] shows that QSUC reduces oscillation in output, but its working area is within 90% efficiency range and lower VTG value compared to other topologies [17, 18, 20,21, 27, 21, and 28]. Structures having switching inductors in their topologies [21, 22, 24- 26, and 28] and multi-level structures using switched capacitors [21, 22, 24- 26] are utilized to boost the converter's gain. Voltage double is used before the output in some topologies to minimize stress and boost voltage gain at the expense of increasing the number of components [15, 17, and 27]. Most topologies have quadratic gain voltage and employ one switch, but [17, 26, 27, 30 and 32-34] use two semiconductor switches, which makes the circuit complex and expensive. The challenges connected with coupled inductor leaking inductance are solved in [21] without the use of a snubber circuit. Esmaeili et al, develops a converter with a voltage double for obtaining very high voltage [28]. Most designers' topologies utilize Voltage Multiplier Cells made of switched capacitors and inductors to boost the VTG, which is a drawback. These converters rely on at least 2-switch that can be operated at the same or various duty cycle. These converters must be used with caution since they can become unstable at lower duty ratios close to the higher limit. The VTG relations show that the given quadratic boost converter can extent high VTG, and there is no duty cycle ratio limitation. As a result, the duty cycle of the [1, 15, 17, 20, 21, 26, 27, 29 and 31-34] converter can be set to the maximum value (0.8-0.95). Quadratic set-up converters- (QSUCs) produce high voltage transfer gain at low duty ratio range [14, 16, 18 ,23-25, 28, and 23]. High voltage gain topology with low duty ratios reduces the current and voltage stress can be achieved maximum efficiency up to (90-94) %. To accomplish the high voltage transfer gain, these converters primarily use voltage multiplier cells- (VMCs) and a number of inductors and capacitors. Table 1 summarizes the outcome of this conversation [1], and [13-34].

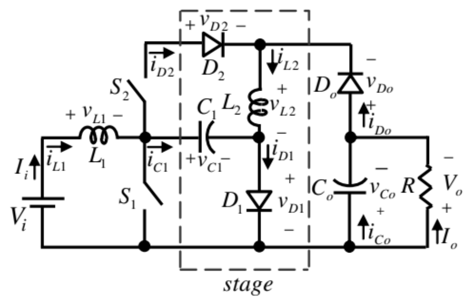
Table 2 depicts the various configurations for building a Q set-up converter with maximum efficiency. According to compassion Table 1, only nine out of twenty-three topologies provide high-efficiency QSU converters. As stated in Table 2, the suggested techniques, the high efficiency QSU converters, are created by including components and employing various connection strategies.

Table 1. Comparison of Quadratic Step-up DC-DC Converter

Ref.	No. Of Components				Total Components	Voltage Transfer Gain (VTG)	Duty Cycle Range (DR)	Maximum Efficiency	Output Oscillation	Complexity	Cost
	Passive		active								
	Inductors	Capacitors	Diodes	Switches							
[1]	2	2	3	1	8	$\frac{1}{(1-D)^2}$	0.1-0.85	90%	High	Less	Less
[13]	2	4	5	1	12	$\frac{3+D}{1-D}$	0.2-0.4	92 %	High	Less	High
[14]	3	3	5	1	12	$\frac{2}{(1-D)^2}$	0.2-0.4	92%	High	Less	High
[15]	3	2	3	1	9	$\frac{D}{(1-D)^2}$	0.7-0.85	91.4%	High	Less	Less
[16]	3	3	5	1	12	$(\frac{D}{1-D})^2$	0.35-0.6	90 %	High	Less	High
[17]	2	2	3	2	9	$\frac{1}{D(1-D)}$	0.5-0.95	93%	High	High	Less
[18]	2	4	5	1	12	$\frac{2}{(1-D)^2}$	0.0-0.7	94%	High	Less	High
[19]	3	3	5	1	12	$\frac{2}{(1-D)^2}$	0.0-0.72	91.5%	High	Less	High
[20]	2	4	5	1	12	$\frac{(2-D)^2}{(1-D)^2}$	0.1-0.8	94%	High	Less	High
[21]	2	5	6	1	14	$\frac{2(2-D)}{(1-D)^2}$	0.1-10.8	94.5%	Less	High	High
[22]	3	4	4	1	12	$\frac{(1+D)}{(1-D)^2}$	0.0-0.5	88.24%	Less	Less	High
[23]	2	4	5	1	12	$\frac{2}{(1-D)^2}$	0.0-0.6	91%	High	High	High
[24]	4	6	9	1	20	$\frac{4}{(1-D)^3}$	0.1-0.59	91.6%	Normal	High	High
[25]	3	4	6	1	14	$\frac{(D+D_1)(3D_1+2D)}{{D_1}^2}$	0.6-0.65	91%	High	High	High
[26]	4	4	6	2	16	$\frac{1}{(1-D)^2}$	0.0-0.82	92%	High	High	High
[27]	2	2	2	2	8	$\frac{1+D-D^2}{(1-D)^2}$	0.1-0.8	94%	High	High	Less
[28]	4	4	4	1	13	$\frac{n-1+nD}{(1-D)^2(n-1)}$	0.0-0.78	94%	High	High	High
[29]	4	3	4	1	12	$\frac{(n+1)(2-D)}{(1-D)^2}$	0.0-0.6	94.3%	High	High	High
[30]	2	4	4	2	12	$\frac{(3-D)}{(1-D)^2}$	0.0-0.7	91%	Less	High	High
[31]	2	2	2	1	7	$\frac{1+N}{1-D}$	0.1-0.9	95%	High	Less	Less
[32]	8	6	8	2	24	$\frac{(3+2n)}{(1-D)^2}$	0.5-0.85	95%	Less	High	High
[33]	2	3	3	2	10	$\frac{(1+D)}{(1-D)^2}$	0.1-0.8	92%	High	High	Less
[34]	2	4	4	2	12	$\frac{1}{(1-D)^2}$ $\frac{1}{2(1-D)}\left[\frac{2-D}{1-D}\mp\sqrt{\frac{(2-D)^2}{(1-D)^2}+\frac{8D}{2L/R_LT}}\right]$	0.1-0.8	94%	High	High	High

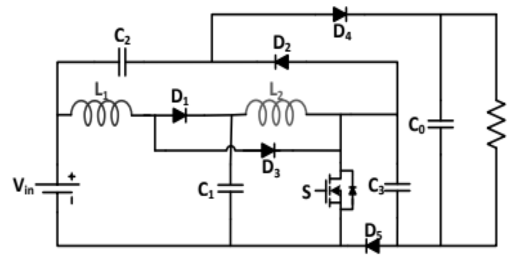
Table 2. Proposed QBC Techniques

QBC Techniques



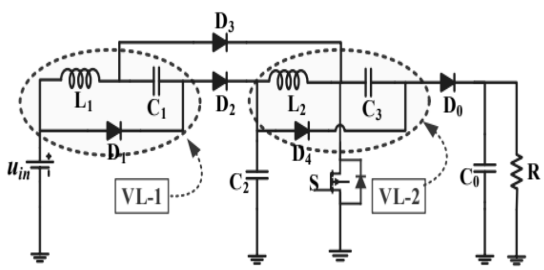
[17]

- Two switches that operate in opposition to one another are managed by the PWM approach.



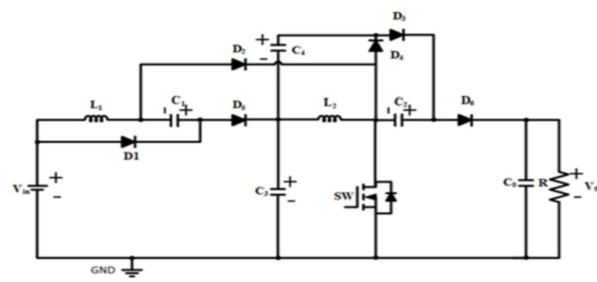
[18]

- Three duty cycle models were proposed (0.0–0.7), and model III's 16 components allowed for a maximum voltage gain of 45.



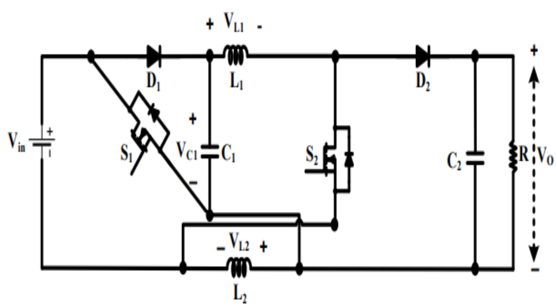
[20]

- Voltage gain up to 35 and controlled duty cycle range 0.1-0.8.
- voltage stress on switch ($\frac{V_S}{V_{in}}$) $=\frac{2-D}{(1-D)^2}$



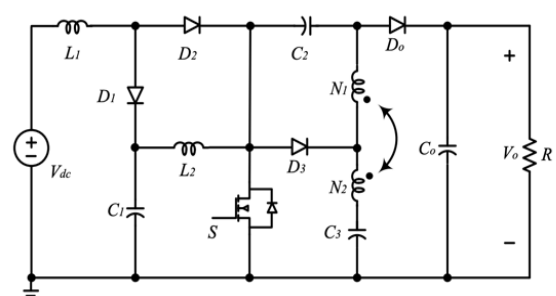
[21]

- Voltage gain up to 60 and D cyle up to 0.8.
- voltage stress on switch ($\frac{V_S}{V_{in}}$) $=\frac{2-D}{(1-D)^2}$



[27]

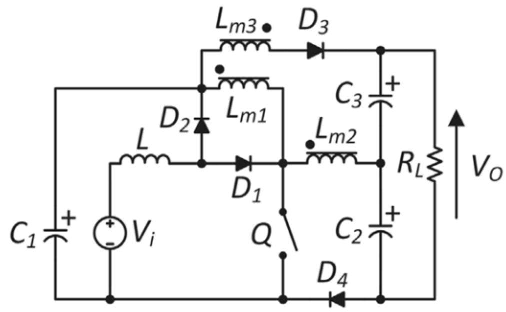
- Voltage gain up to 35 and D control value up to 0.8.
- voltage stress on switch ($\frac{V_S}{V_{in}}$) $=\frac{1}{(1-D)^2}$

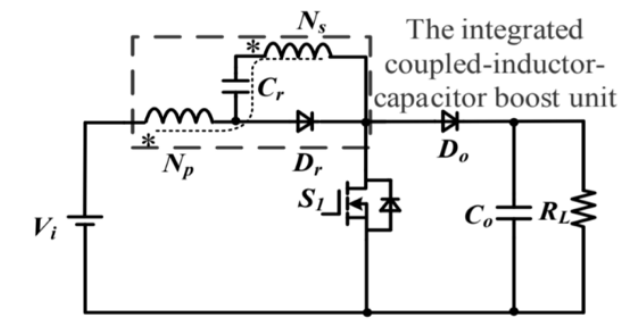


[28]

- In a traditional SEPIC (single ended primary-inductor converter) design, a linked dual winding transformer with a turn ratio of n =(N1/N2) takes the place of the intermediate inductor.

voltage stress on switch ($\frac{V_S}{V_{in}}$) $=\frac{(n-1)V_O}{n-1+nD}$



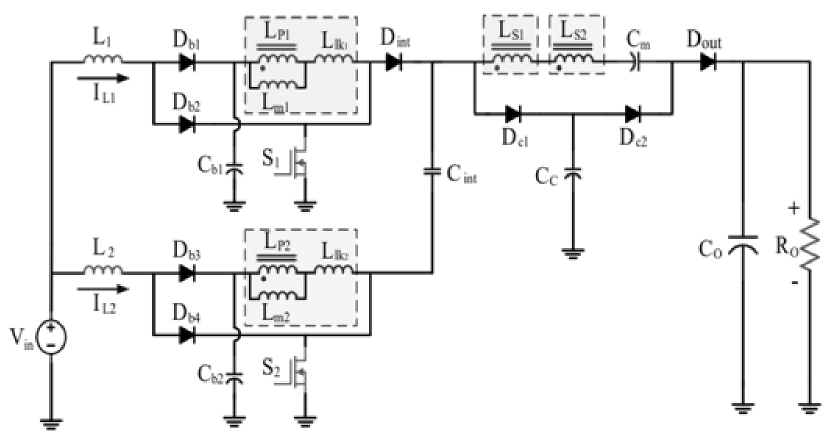


[29]

- Voltage gain up to 25 and D control value up to 0.6.
- voltage stress on switch ($\frac{V_s}{V_{in}}$) =$\frac{1}{(1-D)^2}$

[31]

- Due of its low voltage gain, a switching capacitor is added and it is adjusted. The turns ratio ($\frac{N_s}{N_p}$) of the connected inductor can be changed to get a higher voltage gain.
- Voltage gain up to 10, and 40 with turns ratio N=0, and 3, respectively.



[32]

- Voltage gain up to 225 with n=1 and D= 0.85.
- voltage stress on switch ($\frac{V_s}{V_{in}}$) =$\frac{1}{3+2n}$

4 Summary

This overview section discusses the benefits and limitations of the methodologies most commonly used to derive high voltage transfer gain (VTG) topologies, and it will serve as a roadmap for researchers beginning their topological derivation study. For photovoltaic (PV) sources, a high gain, high efficiency converter is required. The study expanded in this research to include the restrictions that were taken mainly during the survey of recent research in the same field, in addition to the basic analysis that was conducted on the converter. Furthermore, the grade of the hardware setup in terms of efficiency is provided. Table 1 contains the above-mentioned details, as well as references, for all four gain augmentation strategies. Because the high gain DC-DC converter disclosed in the research is suggested for distributed power production systems, Table 3 discusses the role of power converters in renewable energy (RE) applications as well as gain improvement approaches.

Table 3. Aims of The Presented PV QSUC Systems

Ref.	Technique For Topology Derivation	Aims	Application
[1]	A synthesis procedure based on a matrix representation of DC-DC converters topologies [35].	-High ratio of conversion and perfect efficiency for a wide range of input source voltage.	PV system/ photovoltaic grid connected system.
[15]	Modified the conventional SEPIC.	-Input current in continuous mode, maximum voltage gain.	Renewable Energy
[20]	Voltage Lift Technique-VLT	-High voltage gain, reduced number of components, High efficiency.	Renewable Energy Sources (RESs)
[21]	Non-isolated category with a common ground (CG)	-High voltage gain, lower duty ratio, high efficiency.	Renewable Energy
[22]	Multistage Switched Capacitor (SC), voltage multiplier cell (VMC).	-High voltage gain	Solar Photovoltaic systems
[23]	Non-isolated voltage lift cell (VLC) high-gain converter depending on RC snubber circuit.	-High voltage gain, lower number of inductors, reduce reduced duty cycle and voltage stress across a switch.	PV Application
[24]	Voltage Lift Technique -VLT and Voltage Multiplier.	-Voltage stress on the switching device half the output voltage, small input and output current ripple, higher voltage gain	Renewable energy sources (RES/PV)
[31]	Integrated coupled inductor-capacitor technique.	-High efficiency, uncomplicated design.	Renewable Energy

5 Future Scope

Most of the cited research articles show that the researchers are focused on deriving the topology with: high voltage transfer gain, lower duty cycle limits, high efficiency, small input and output oscillation, low voltage and current stress on the power semiconductor switching devices, minimally number of components to get simple structure and electronic design (low cost and complexity), discuss the operating topology on different modes (ideal and non-ideal, as well as continuous and dis-continuous current modes (CCM, DCM)), and the losses occurring in various components.

The majority of the Study on the derived topology has been done using steady-state analysis as a result of this consolidation. Within the practical environment, the converter must be studied and there is a necessary to design a control unit to obtain expected results for the desired outcomes. Table 4 delineates the prospective research avenues for high gain DC-DC converters. Most research relies on a basic control structure, namely the PI-controller, to provide a rapid dynamic response and eliminate steady-state faults, while maintaining a constant output voltage despite variations in load or input voltage [1] [20] [36] [37].

The issues faced by this controller include the precise development of a linear mathematical model [38] and the satisfying functioning of the controller amidst various disturbances [36]. This indicates a significant opportunity for the creation of a mathematical model aimed at designing a controller characterised by simplicity and anticipated outcomes.

In addition, it is clear from the proposed study that will be a future interest by researchers towards reducing the oscillation within a steady state (SS) stage and time requiring to reach it. So, new controlling approaches in this direction can be induced for techniques described in the study, which makes it a more ideal level of performance. This article as a guide for the researcher not only throws light on the comparison between the design of high-gain boost converter topologies, but with the knowledge gained from this article, attention is given to the most important problems that the researchers faced such as the difficulty in the mathematical derivation of the high gain converter, control unit, efficiency ratio, duty cycle limits, etc. Future researchers will gain from a thorough comprehension of the many kinds of high-gain converters present in the existing literature. The same principle may be used to many isolated DC-DC converters for enhanced comprehension. This study proposes possible techniques for administering potent and active chemicals for significant enhancement.

Table 4. deductions from the Proposed Study and Scope Future

Deductions From the article Mentioned	Scope future point
• In most cases of analysis, the stable operating condition is adopted. • Most suggested application is photovoltaic (PV) application, and some researchers directed to introduce other applications [34]. • Most research used PI to achieve a fast dynamic-response and zero steady state- SS faults. • In general, derived topologies are thoroughly examined in CCM and DCM. • Design of various high gain cells. • Depend on PWM technique and others used MPPT control methods. • Efficiency analysis with respect to losses calculation.	• Take the opposite technique for static analysis (Dynamic analysis) searching for vulnerabilities with controller design. • Decreases number of components used within converter design so cost analysis required. • Usage controlling method to reduce input/output oscillation and spent time to reach steady state operation. • Adding different applications for this type of high gain voltage converter. • Study on power factor and reliability study. • Derivation of high gain bi-directional DC-DC converter.

This may thus be extended to include novel topological designs. This study may be extended to examine the error propagation of the proposed high-gain converter classes.

6 Conclusion

This article presented a comprehensive study on the latest research that was presented regarding the quadratic step-up DC-DC converter (Q**SU**C), in addition to presenting tables and a detailed explanation between the proposed research for the study and knowing the baseline behind the similarities and differences between them. So, to make it simpler for future researchers to decide what can be provided and added to prevent the noted flaws, a comparison of the proposed Q**SU**C- research articles have been presented. From the study, the following can be observed:

- Most of the researchers depended on increasing the number of converter components to obtain high voltage transfer gain of the converter. However, it leads to a high component count which means an increase in complexity and cost.
- To increase efficiency and reduce the number of converter components, replacement technology can be adopted.
- Most of the researchers relied on studying the behavior of the system during the steady state operation, neglecting the time required to achieve an optimal state of stability, so necessary to get rid of the input/output oscillation.
- Most of the research was directed to photovoltaic energy systems as an applied example of this type of converter, so, it is important introducing modern applications (such as: Avionics, PV-Grid integration, UPS, and Telecommunication database/ DB systems) within the scope of adopting this type of converter (Q**SU**C).
- Researchers rely on the use of easy types of controller systems such as: PWM, PI, PID, While Problems encountered by this controller are accurate linear mathematical model derivation.
- Through the explanation provided in this article and the comparison of the efficiencies of the proposed Q**SU** -converters, future researchers can determine the destination from which they will start to drive the new topology.

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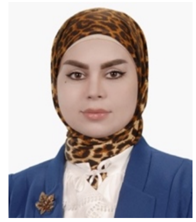
Biography



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