Novel Topological Derivations for DC-DC Converters

Mahajan Sagar Bhaskar [1], Pandav Kiran Maroti[2] and Draxe Kaustubh Prabhakar [3]

[1,2,3] **School of Electrical Engineering, Vellore Institute of Technology, Chennai – 600127, Tamil Nadu, INDIA**

[2] **School of Electrical Engineering, Vellore Institute of Technology, Chennai-600127, Tamil Nadu, INDIA**

[3] **School of Electrical Engineering, Vellore Institute of Technology, Chennai-600127, Tamil Nadu, INDIA**

Abstract

This paper presents various syntheses of different types of possible circuit topologies of two state DC-DC converters which are suitable for photovoltaic applications. In this paper 12 two state DC-DC converter topologies are introduced, including four new topologies with their respective gain. These circuit topologies are derived by using set of general requirements concerning both structure and operation of two state DC-DC converters. These four new circuit topologies are designed for 240W rated power, 24 V input voltage and switching frequency is 10 KHz. The results are verified using MATLAB/SIMULINK.

Keywords: *Circuit topology, capacitor and inductor, DC-DC converter, tree, sub-tree, type I vertex, type II vertex.*

1. Introduction

In recent years the rising demand for photovoltaic modules has increased because energy resources and their uses will be a prominent issue of this century. There are several form of zero-pollution renewable energy resources, including solar, wind, bio and geothermal. Solar energy is freely available and easily converted into electrical energy by using photovoltaic cell [1]-[2]-[3]. The output voltage and current of photovoltaic cell will be at low level. This must be stepped up and stepped down for practical applications and grid connection. Hence for generating more voltage and current, photovoltaic cells are cascaded in series and parallel respectively [2]. But series and parallel connection of array is not viable solution, hence DC-DC step up and step down converter is essential.

The family of two state DC-DC converters has been considerably increased by leaps and bounds. There are three basic types of DC-DC converter, Buck, Boost, Buck-Boost. Buck converter is used for generating low voltage from high voltage. Boost converter is used for generating high voltage from low voltage. Buck-Boost provides an output voltage that may be high or less than the input voltage [3]-[4]. These basic converters needed a single inductor. Cuk, SEPIC, UP, DOWN, ZETA and many others converter topologies needed two inductor for designing [1]-[6]-[7]. The gain of different converter is given in Table 1.

Table1. DC-DC converter with their respective gain

No	Name of converter	Gain
1	Buck	D
2	Boost	1 / (1-D)
3	Buck-Boost	-D / (1-D)
4	Cuk	-D / (1-D)
5	SEPIC	D / (1-D)
6	ZETA	D / (1-D)

DC-DC converters are divided in two types; one without sub-tree and with sub-tree. General topology of DC-DC converter is shown in Fig1. Every DC –DC converter consist main tree, but sub-tree is optional for designing.

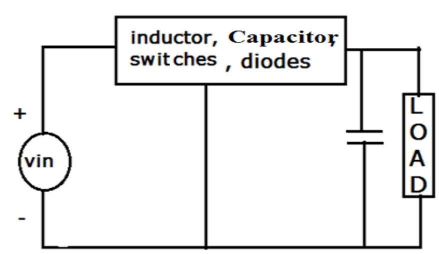
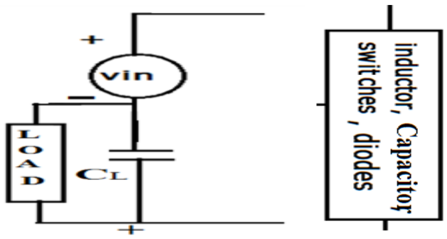


Fig1. General topology of DC-DC converter

2. Rules for Circuit Arrangement

2.1 Main Tree and Sub Tree

Main tree consist a branch of input voltage and load with load capacitor. For every DC-DC converter main tree is necessary. Sub-tree consist a combination of inductor, capacitor, switches and diodes.



(a) Main tree (b) sub-tree

Fig2. Main tree and sub-tree

2.2 Vertices

Nodes present in the circuit are called vertices. There are two types of vertices; Type I vertex and Type II Vertex. Type I vertex is node of main tree and Type II vertex is node of sub-tree.

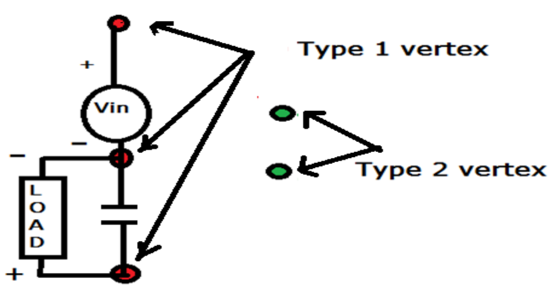


Fig3. Type I and II vertex

2.3 Rules

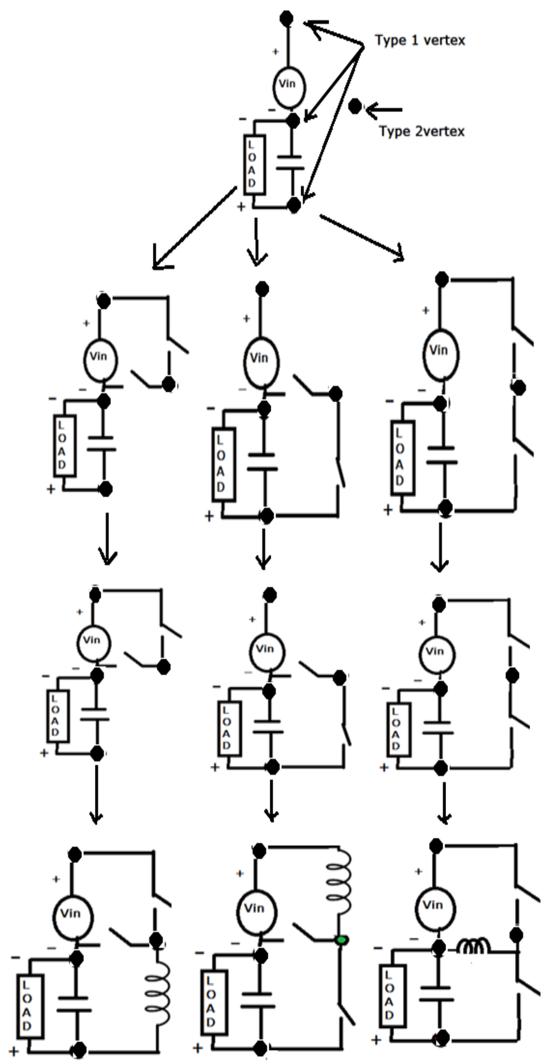
There are four types of rules for designing the circuit topology arrangement.

1. Each of Type I vertex is connected at least with one L (Inductor edge) or S-type edge (Switch edge).
2. Each of Type II vertexes is connected with at least one S- type edge together with exactly one L-type edge.
3. The L-type edges do not occur in parallel with the S-type edges.
4. Capacitor is present between two adjacent Type II vertexes.

3. Circuit Arrangement of DC-DC converters

The circuit arrangement without sub-tree is shown in Fig4 (a)-(c). Buck, Boost and Buck-Boost converters are present into the category of without sub-tree. Even sub-tree is not present but one Type II vertex is needed for connection that means this category needed exactly one TYPE II vertex.

The circuit arrangement with sub-tree is shown in Fig5. Cuk, SEPIC, ZETA, UP, DOWN and four new converter topology are designed into the category of with sub-tree. These four new types are designed by cross arrangement. These types of converter needed at least two Type II vertices.



(a) Buck (b) Boost (c) Buck-Boost

Fig4. (a)-(c) Circuit arrangement of DC-DC converter without sub-tree

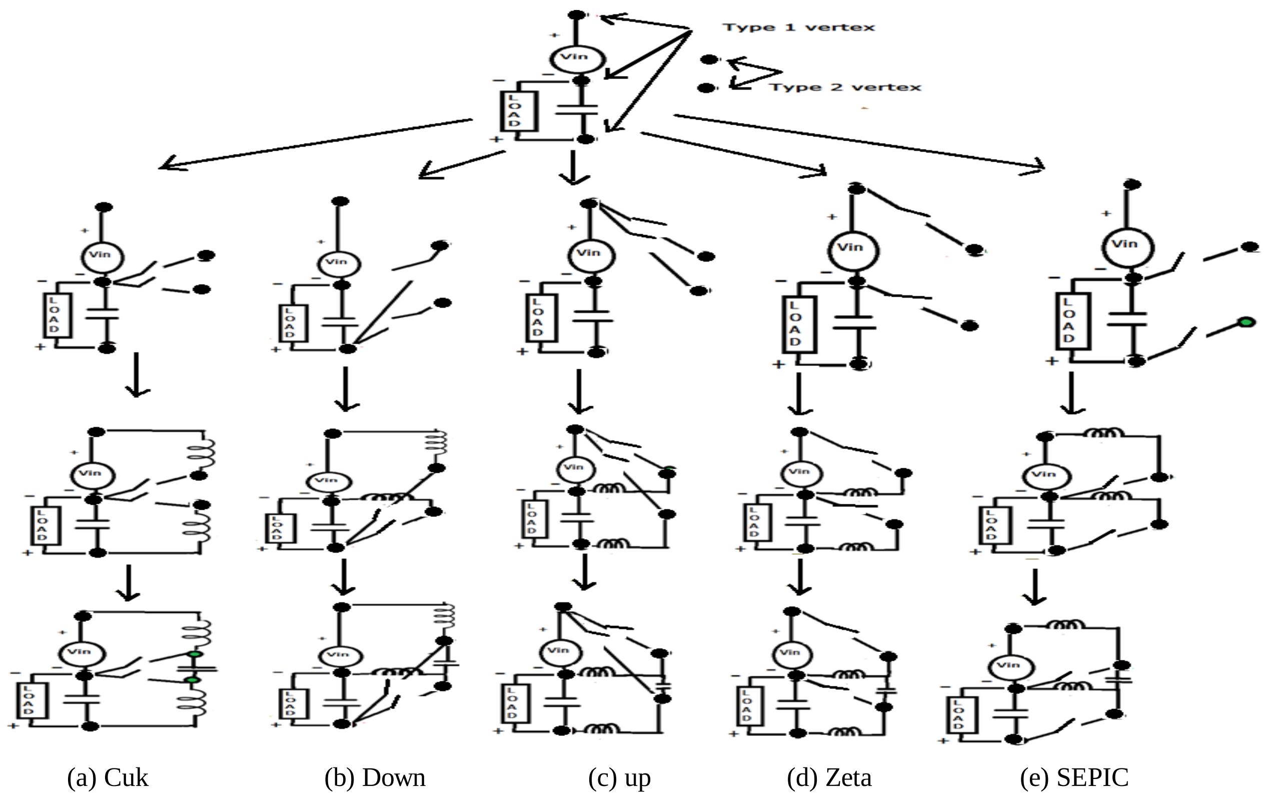


Fig5 (a)-(e) circuit arrangement of DC-DC converter with sub-tree

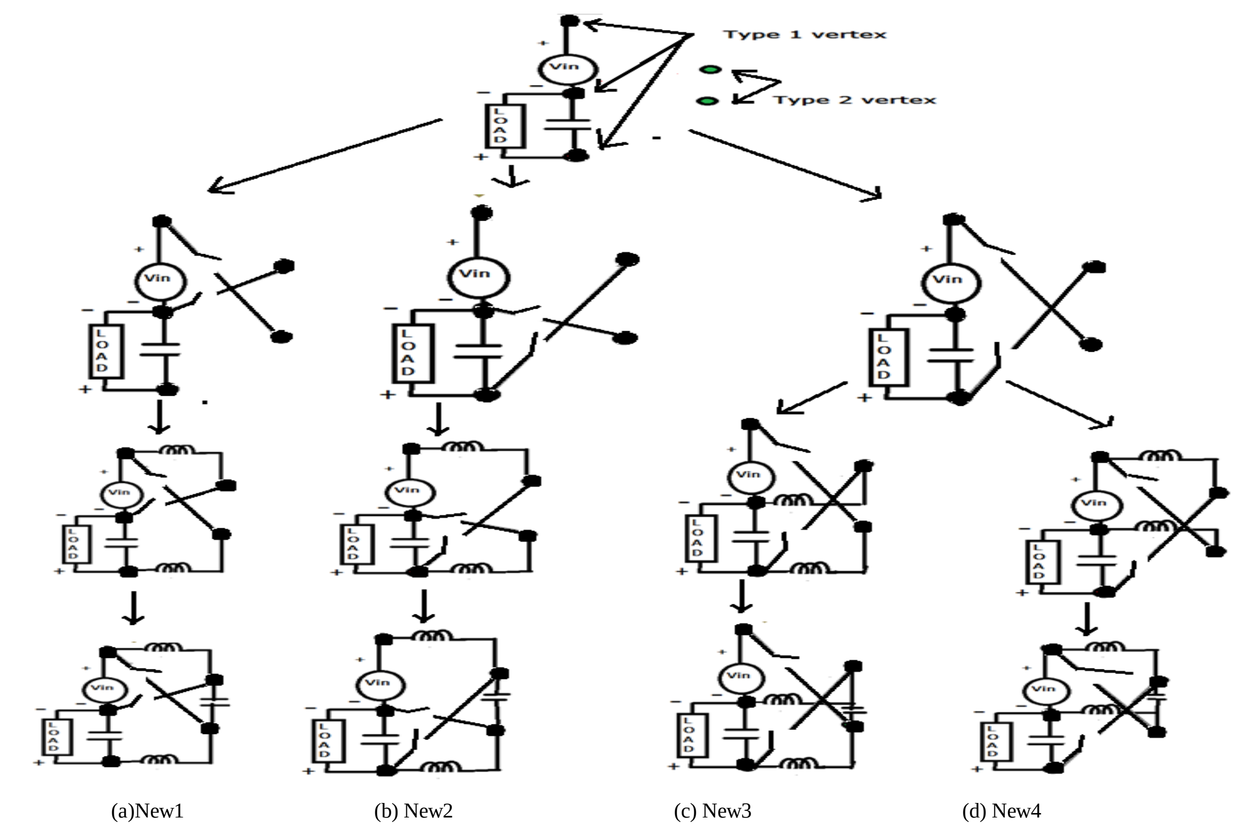
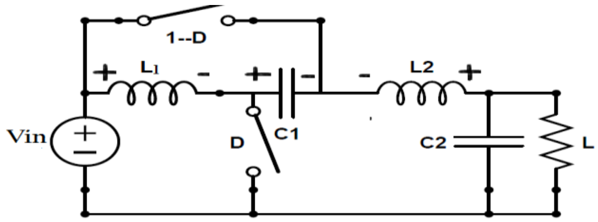
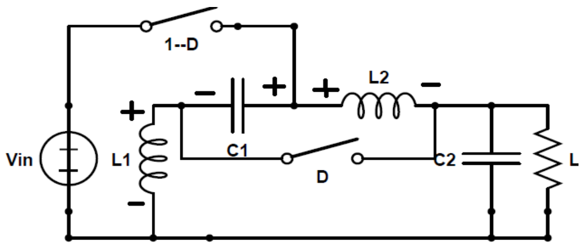


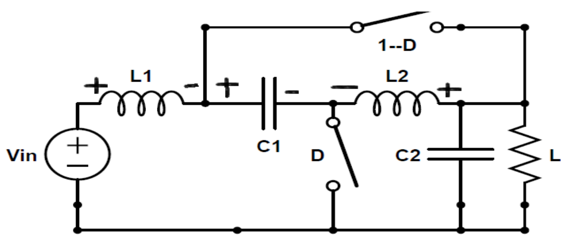
Fig6. (a)-(d) circuit arrangement of DC-DC converter with sub-tree cross arrangement.



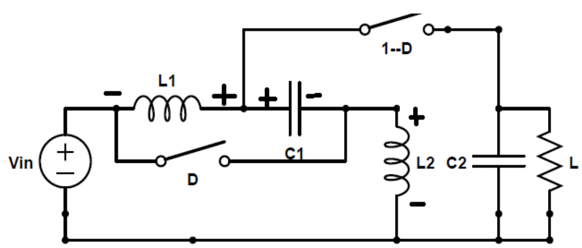
New 1



New 2



New 3



New 4

Fig7. Four New topologies

Fig7 shows power circuit of four new topologies. Table 2 shows the gain of new topologies. The gain of New1 and New4 topology is exactly same. Similarly the gain of New2 and New3 topology is exactly same.

Table2.gain of new topologies

No	Topology	Gain
1	New1	(1-2D) / (1-D)
2	New2	(1-D) / (1-2D)
3	New3	(1-D) / (1-2D)
4	New4	(1-2D) / (1-D)

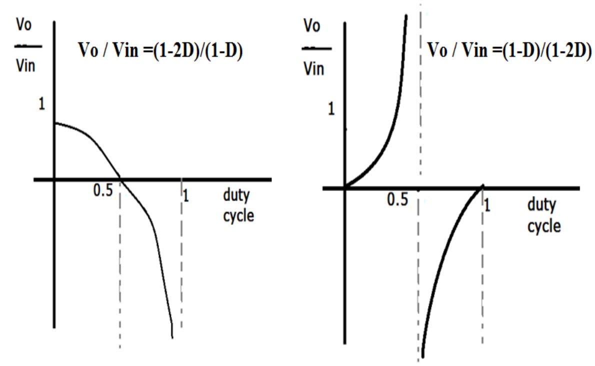


Fig.8 graph of gain vs duty cycle

4. Simulation Results

The new topologies with the designed parameters value is simulated in MATLAB/SIMULINK. The parameters values are listed in Table no3.

Table1. Designed parameters value

No	Parameters	Value
1	Input Voltage(New1,new2, New3, New4)	24 V
2	Output Voltage	- 48V(new1,New4) and 72V(New2,New3)
3	Output power	240 W
4	Load	9.6 Ω(new1,New4) and 21.6Ω (New2,New3)
5	Inductor (L1 and L2)	180uH and 150uH
6	Capacitor	200uF
7	Duty Cycle	0.75(new1,New4) and 0.4(New2,New3)

These four new topologies operate on two switches which are complementary to each other. Type New1 and New2 topology give higher gain at extreme duty cycle and lower gain at duty cycle 0.5, whereas type New2 and New3 topology give higher gain at duty cycle 0.5 and lower gain at extreme duty cycle.

Type New1 and New2 topology is simulated for 75% duty cycle; it gives output voltage of -48V for 24V input. It gives negative voltage gain of 2, as shown in Fig.9. Type New2 and New3 topology is simulated for 40% duty cycle, it gives output voltage of 72V for 24V input. It gives positive voltage gain of 3 as shown in Fig.10.

The gain of these topologies is depends on duty cycle. These gives negative gain at duty cycle more than 50% and positive gain at duty cycle less than 50% as shown in Fig.8.

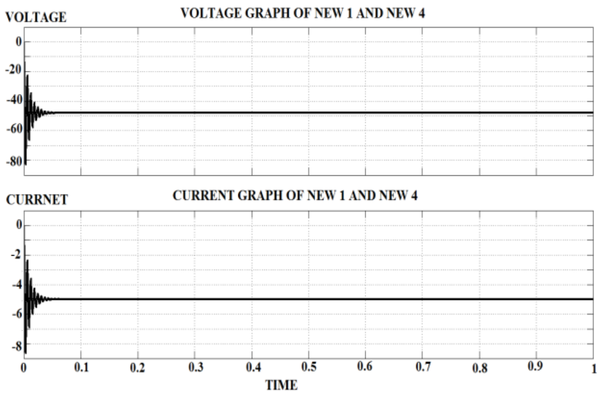


Fig.9 Output voltage and output current waveform of New1 and New4 topology.

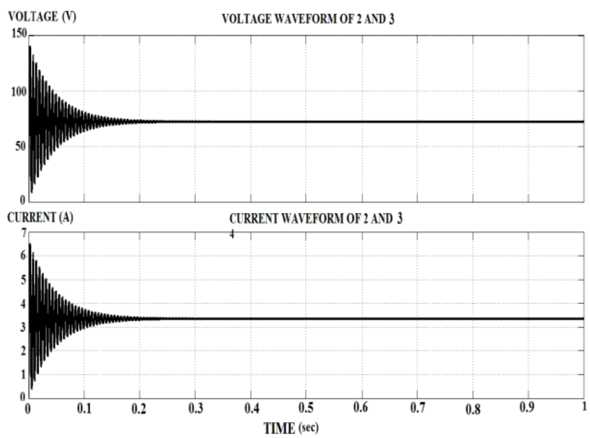


Fig.10 Output waveform and current Waveform of New2 and New3 topology

5. Conclusion

In this paper four new topologies of two state DC-DC converters are introduced by following the proposed set of rules. Type New1 and New4 topology have same gain and New2 and New3 topology have same gain. These topologies are successfully simulated and output waveforms show that these are having desirable characteristics of converters for photovoltaic applications.

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Mahajan Sagar Bhaskar is born in Jalgaon, Maharashtra. Currently he is pursuing Master Degree in Power Electronics and Drives at VIT University, Chennai. He received his Bachelor Degree in Electronics and Communication Engineering in the year 2011 at Bharati Vidyapeeth affiliated to Mumbai University, Maharashtra. His research interest is modeling, analysis of converters and power electronics.

Pandav Kiran Maroti is born in Aurangabad, Maharashtra. Currently he is pursuing Master Degree in Power Electronics and Drives at VIT University, Chennai. He received his Bachelor Degree in Electronics and Tele-Communication Engineering in the year 2011 at Hi-Tech Institute of Technology, Aurangabad affiliated to Dr. Babasaheb Ambedkar Marathwada University, Maharashtra. His research interest is DC-DC converter and Multilevel Inverter.

Draxe Kaustubh Prabhakar is born in Gadhinglaj, Maharashtra. Currently he is pursuing Master Degree in Power Electronics and Drives at VIT University, Chennai. He received his Bachelor Degree in Electronics Engineering in the year 2012 at Finolex Academy of Management and Technology, Ratnagiri affiliated to Mumbai University, Maharashtra. His research interest switched mode power supply, converters, inverters and digital electronics.