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MULTIPLE-SOURCE SINGLE-OUTPUT BUCK-BOOST DC–DC CONVERTER WITH INCREASED RELIABILITY

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ABSTRACT

DC-DC converters provide a major contribution in today's power electronics world. They find use in many applications like renewable energy resources which include solar, wind, fuel cell and so on. Renewable energy sources mainly depend on climatic conditions and will be varying in nature. To get a stable DC voltage, we can use various kinds of renewable sources simultaneously. Among the different kind of DC-DC converters, multiport DC-DC converter is a kind of DC-DC converter which becomes popular in use because of its efficiency, reliability, use of less number of components, reduced cost and also due to the production of more number of outputs with either a single input or by multiple inputs. By using a multiport DC-DC converter we can obtain different levels of voltages from a single converter itself which finds its usage in applications like an electric vehicle, renewable energy, etc. In this paper, a study regarding different topologies of multiport DC-DC converters with single input and multiple outputs is discussed. These converters are compared at the end and their advantages and disadvantages are also explained.

KEYWORDS: Voltage gain, Zero voltage switching, Coupled inductor, MPPT, SEPIC converter.

I. INTRODUCTION

Nowadays, DC-DC power converters play main role in the field of power electronics. During the last years in the power electronics field & the progresses marked in this field paved the way for the progress of multiport converter (MPC) topologies [1]. They have single or multiple inputs & output ports to which power supplies & loads can be connected as in Figure 1. The basic criteria for MPCs include high efficiency, reduced size & cost. MPCs are widely demanded in renewable energy resources (RES), electric vehicles (EV) personal computers & provides energy flow, voltage regulation between various inputs & outputs which makes the whole system simpler & more compact with reduced no. of components [2]. MPCs may be grouped as the function of input & output numbers as multi input-multi output (MIMO), multi input-single output (MISO) & single input-multi output (SIMO) converters. Second classification of MPCs include isolated type & non-isolated type. There is no galvanic isolation for non-isolated MPC within different ports & depending on the number of inductors they can be further categorized into single inductor MPC (SI-MPC) or multiple inductor MPC (MI-MPC). Multiport converters with only one input source has been investigated in this study on the basis of voltage gain, duty ratio, switching frequency, power conversion efficiency & no. of power switches used [3].

Fig-1: Basic block of multiport converter (SIMO Topology)

II. DUAL OUTPUT DC-DC CONVERTER WITH FLYBACK TOPOLOGY

In [4], a novel integrated DC-DC converter section which produces a step-up output & a step-down output is discussed. Both the outputs are regulated simultaneously by establishing a better controlling strategy. Comparing with discrete type configurations, here this converter prefers reduced count of switches. For boost stage, the converter offers an increased boost ratio & is able to clamp the switch voltage spikes. For step-down stage, steady state performances & the dynamic performances same as that of conventional type buck converter

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and also the port of step-down output can be extended to multiple ports in which the SIMO version of converter can be obtained. The origin of this converter is from the conventional type flyback converter. As in Figure 2, secondary of flyback topology a voltage-doubler rectifier circuit is included & also to form a parallel-input- series-output configuration a bidirectional boost converter is incorporated. By adding switch Q_2 in series with Q_1 plus a LC filter circuit,astep-downoutputportisformed.BycontrollingthedutyratiosofQ1-3,simultaneouslytheconverteroffershigh step-up output & a step down output. Soft switching of every switches are carried on by the usage of the intermediate bidirectionalbooststructure.

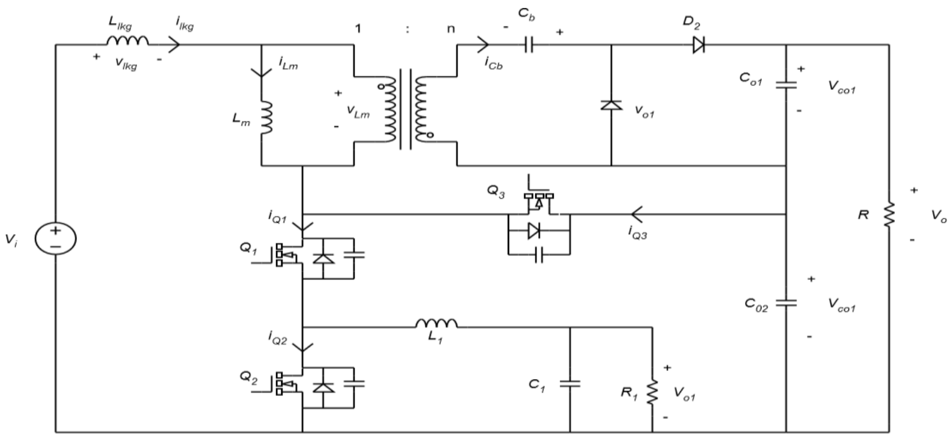

Fig-2: Flybackbasedsingleinputdualoutputconverter

a) Advantages

- Highswitchingfrequency
- Providesswitchvoltagestressclamping
- Reducedswitchinglosses
- Independentcontrolofdualoutputs
- Extensioncapabilitytomultiplestep-downoutputports.

b) Disadvantages

- Moreelectromagneticinferenceduetogap
- Increasedripplecurrent
- Increasedsize&cost.

III. ISOLATEDBIDIRECTIONALBUCK-BOOSTCONVERTERWITHSIMO

In [5], a multiple output converter is mentioned here. It is basically an isolated bidirectional based DC-DC converter. Operatesbyenergyreleasing(stepup)orbyenergystoring(stepdown)asinfigure3.Duringtheabovesaidfirststate,it boostsvoltagefrominputsourcetoahighvoltage&middlevoltage.Excessenergyavailableathighvoltagesidewillbe transmitted reversely. High voltage attained may be opted as main source of power & middle voltage output for auxiliarysourceslikebatterymoduleschargingpurposes.

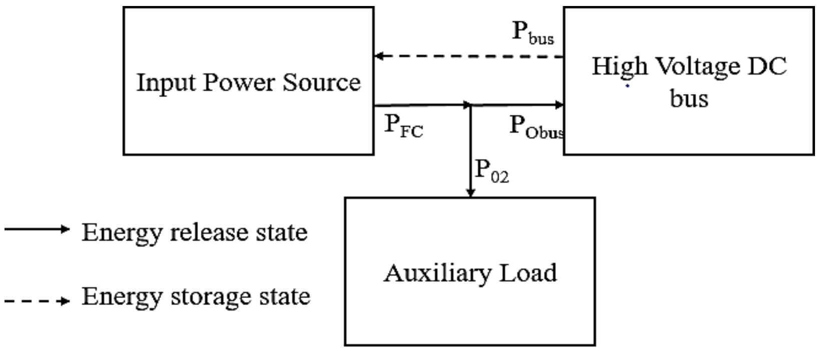

Fig-3: Blockdiagramofbidirectionalpowerflowcontrol

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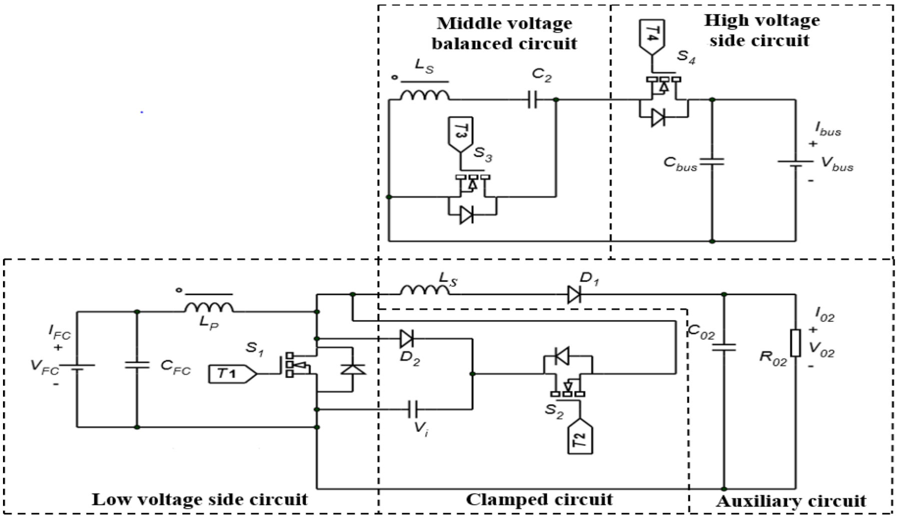

Fig-4: Isolatedbidirectionalconverter

Theworkingofstep-down&step-upstateareconcludedasfollows:

a) Step-downtostep-up

- Receivenormalpowerrequirementatdaytime.
- Decreasetherechargecurrent(I_{FC})tozero.
- Triggerpowerswitchesw.r.ttheswitchingpatternsatstep-upstate.
- Implementtheproportional-integral(PI)voltagecontrolforthestep-upstate.

b) Step-uptostep-down

- Receivetheoff-peakpowerrequirementatnight.
- Decreasethehigh-voltageloadcurrent(I_{bus})tozero.
- Triggerpowerswitchesw.r.ttheswitchingpatternsatthestep-downstate.
- ImplementthePIvoltagecontrolforthestep-downstate.

Converter incorporating coupled inductor secures bidirectional control over power with VC & soft switching characteristics. Henceforth, coupled inductors leakage energy is recycled then delivered to high voltage bus side & auxiliary power sources. So, voltage stresses on power switches is greatly limited. By implementation of ZVS, the switching losses can be reduced to great extent. Therefore, high efficient power conversion, electrical isolation, bidirectionalpowertransfer&differentoutputvoltagesareobtained.

c) Advantages

- High-efficiencypowerconversion
- Provideselectricisolation
- Bidirectionalpowertransfer
- Differentoutputvoltages
- Voltagestresses&lossesduetoswitchingarereducedbecauseofZVSfeatures.
- SimplePIcontrol.

d) Disadvantages

- No.ofpowerswitches(4No.)ismorewhichincreasesthecost.

IV. SIMOBOOSTDC-DCCONVERTER

In[6],acoupledinductorbasedmultioutputconverterthatproducesboostoutputsfromsingleinputis discussed.Uses oneswitch for giving larger power conversion efficiency and step-up ratio with two output voltages which are unlike. Convertersteps up the input voltage to an adjustable high volt DC bus and a middle

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voltage output. Soft switching & VC techniques are implemented to get rid of the losses via conduction & switching. Problems like reverse recovery currents & stray inductance energy inside diodes of the traditional boost converters are resolved, as a result of this so larger power conversion efficiency is attained. By proper design of auxiliary inductor, the voltage across middle voltage output side can be adjusted appropriately. A simple PI control is adopted here for stable controlofoutputvoltageathighvoltDCbus.

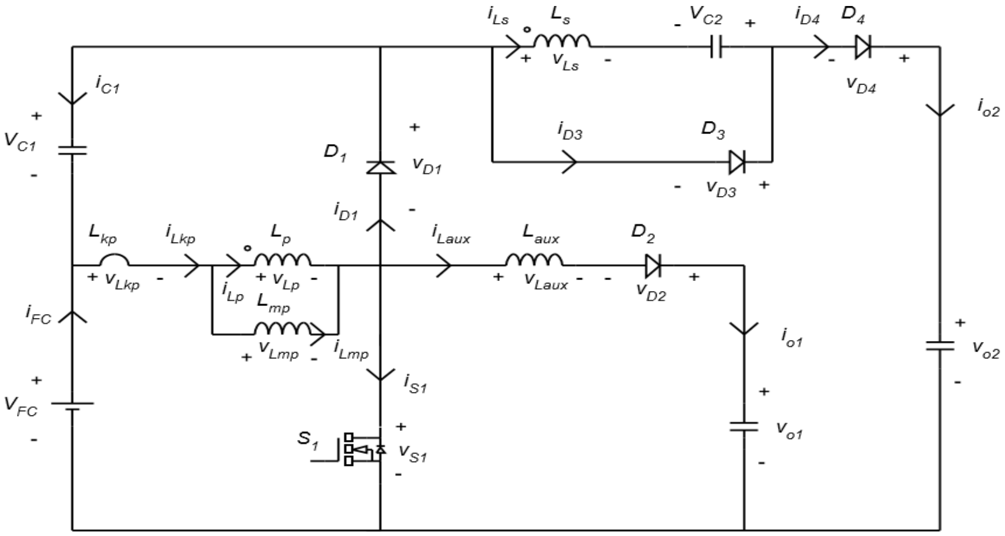

Fig-5: Multipleoutputboostconverter

Highvoltageattainedcanbeimplementedon DC-ACinverterasfrontendterminalorasmainpowerusedinhighvoltage DC loads. Then, middle voltage output secured will be supplying power that is required for charging auxiliary sources likebatteryorforindividualmiddlevoltageDCloads.

a) Advantages

- Usesonepowerswitchtogethigh-efficiency.
- Twodifferentvoltageoutputlevels.
- Voltagestresses&lossesduetoswitchingareminimizedduetoZCSfeatures.
- SimplePIcontrol.
- Usedforapplicationsthatrequireonecommonground.

b) Disadvantages

- Clampingcapacitorwithlargervalueshouldbechosensothatitisusedforapplicationsthatrequirehigh power.
- NotsuitableforusingasfrontterminalforDC-ACmultilevelinverters.

V. BIDIRECTIONALMULTIPLEOUTPUTBOOSTDC-DCCONVERTER

In [7], a multiple converter that offers large power conversion efficiency, bidirectional energy transmission and high step-up step-down ratios is mentioned here. The bidirectional topology here gives different output by three switch configuration.Takingintoaccountofpowermanagement,thisconverteroperatesstepupstatewhichimpliestheenergy release state and step down state which is the energy storage state. Energy release state will be boosting the low input voltagetoanadjustable DC high voltage bus and middle voltage output. The excess energy present in high-voltage side willbereverselytransmitted.

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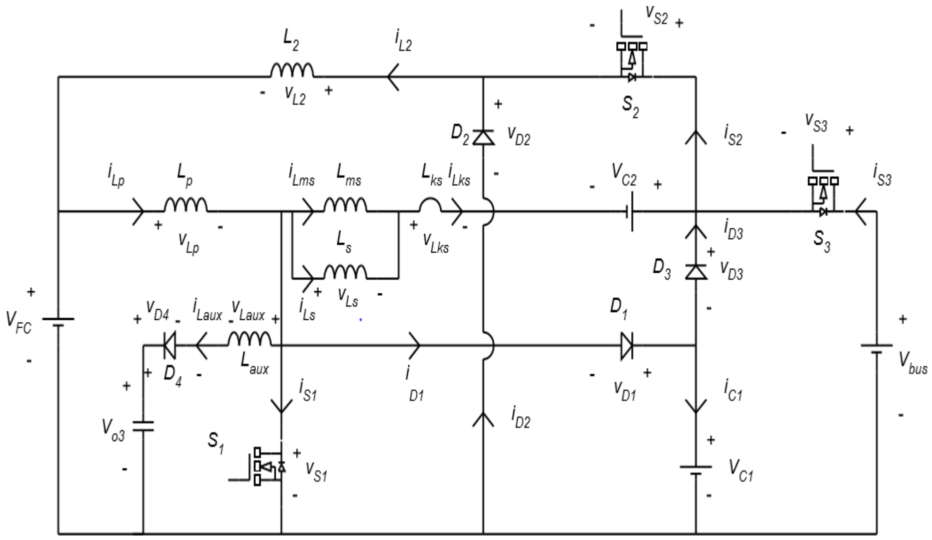

Fig-6: Bidirectionalconverter(Stepdownstate)

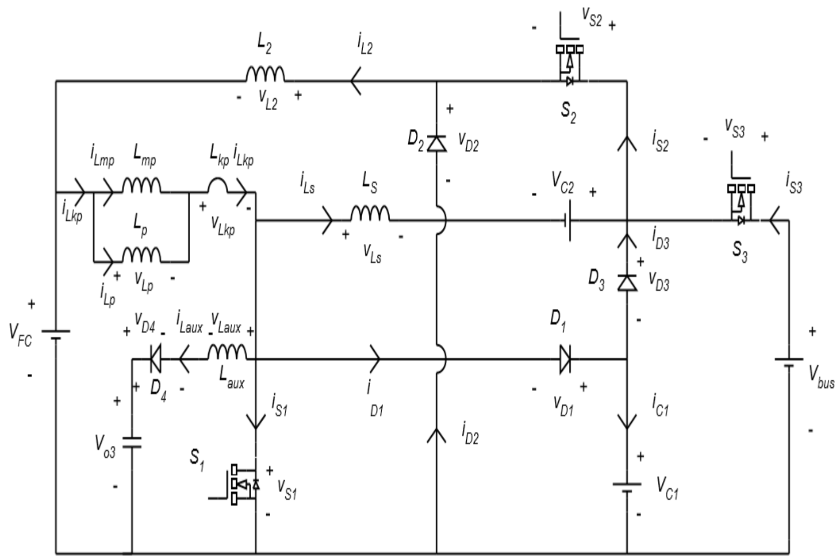

Fig-7: Bidirectionalconverter(Stepupstate)

A coupled-inductor is introduced so as to get the bidirectional control of power with the characteristics of VC, soft switching&similarlythedevicespecificationsaredesignedadequately.Henceforthlargepowerconversionefficiency, bidirectional delivery of energy, large step-up and step-down ratios is secured. Output voltages will be of different levels. The DC high-voltage bus will be acting as main power & middle-voltage output supplies power for separate middlevoltDCloadsorforchargingauxiliarypowersourceslikebatterymodulesconnectedtothecircuit.

a) Advantages

- Adoptsonlythreeswitches
- Step-upandstep-downvoltageratiosincreasedbyusingacoupledinductor.

b) Disadvantages

- Onecannotcontroltheoutputofmiddlevoltageheretobeaconstantvalue.
-

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VI. DUAL-OUTPUTINTEGRATEDCONVERTER

DC to DC based converter that can provide boosted & multiple step down outputs from a single DC input is described in [8]. The non-isolated topology described here is obtained by changing the conventional boost converters controlling switch with a series connected switch. Here step-up state as well as step-down state voltage conversion ratios obtained are same as that of separate boost & buck converters. But comparing with the separate converters this topology uses less numberofswitchingelements.

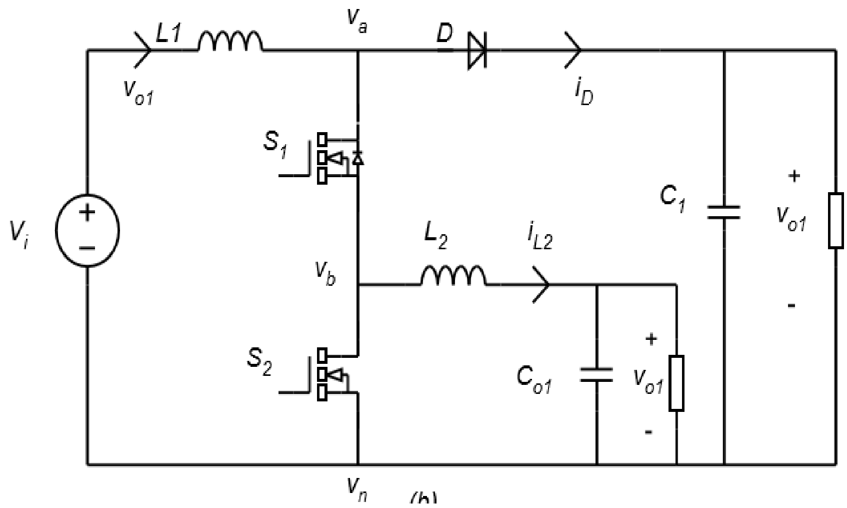

Fig-8: Dualoutputconverter

Attheinputsideandalsoatthestep-downoutputconverterpossesscontinuouscurrents. Therefore, comparing with the conventional buck or buck-boost converter lower input filter is required. Control system here is identical to that of conventional buck and boost converter. The converter possess a broad step-down voltages i.e.; from zero to input voltage (V_{in}) that is achievable at acceptable values of duty ratios. This is because, though the duty cycle D_2 for step-downconversionmaybeverylow.DutyratioofS$_1$ isthesumofD$_1$ andD$_2$,whichhasacceptableoperatingvalues

a) Advantages

i Decreasesconductionlosses.

ii Lessnumberofswitchingelements.

iii Converterhascontinuousinputcurrent.

iv Requirelowerinputfilters.

v Twooutputscanberegulatedseparatelyusingseparatefeedbackcontrolsystems.

b) Disadvantages

- Hardswitchingconditionsdegeneratespowerconversionefficiencytogreatextent.
- Designing oftwo dutycycles for two switches must be carefully done or else it will restrict the range ofoutput voltages.

VII. CUKSEPICTOPOLOGYDUALOUTPUTDC/DCCONVERTER

In [9], a Cuk SEPIC topology based DC-DC converter consisting of dual output is mentioned here. Reduced number of inductors & capacitors are used when compared with separate converters. This converter finds usage in places where supply with more than one voltages is available. Here voltage stress of diodes & switches can be reduced to great extent. There is a gradual increase in voltage gain at one of the output side of the converter. The switches in the circuitry controls the output voltages. Topology constitutes mainly of two diodes & two synchronous switches named as Q_1 and Q_2 that operatessynchronously.

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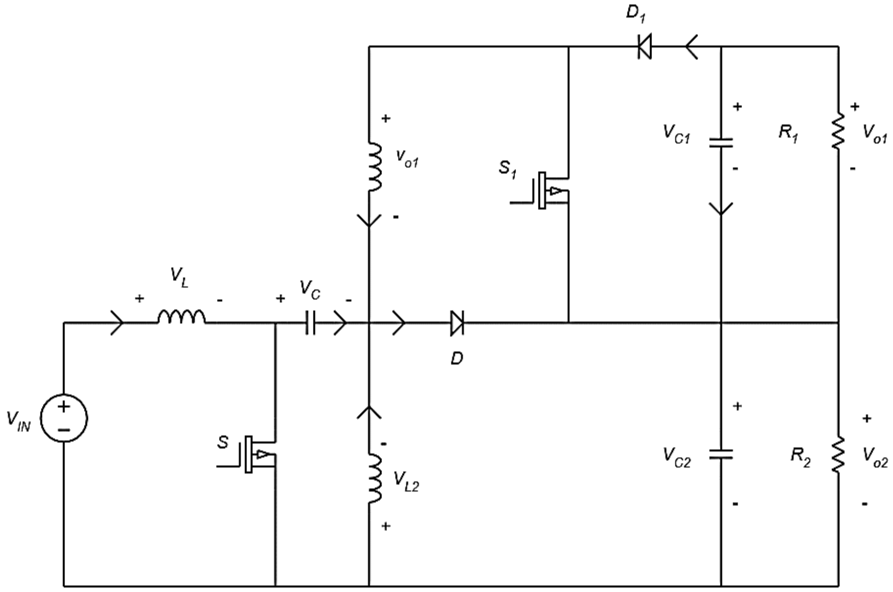

Fig-9: DualoutputSepicCukconverter

a) Advantages

- Continuousinputcurrent
- Improvesoneofthevoltageoutputlevel.

b) Disadvantages

- Highcapacitance&currenthandlingcapabilityisrequired.

VIII. THREELEVELDC-DCCONVERTERWITHDUALOUTPUT

In [10], a novel architecture of three level based DC-DC converter having a single input that produces dual output is introduced here. It can be used for medium as well as high voltage requirements. Converter is a non-isolated type. This topology is formed by the addition of three level based buck converter along with a boost converter whose voltage outputs are simultaneously controlled. This converter lessens the voltage stress over semiconductor elements, provides better efficiency & decreases size of the inductor. As the size of filter capacitor is reduced at step down section along with a small sized film capacitor can be incorporated to get advantages like reduced ESR & more lifespan. To get regulated output voltages along with the capacitors voltage a closed loop control system is designed.

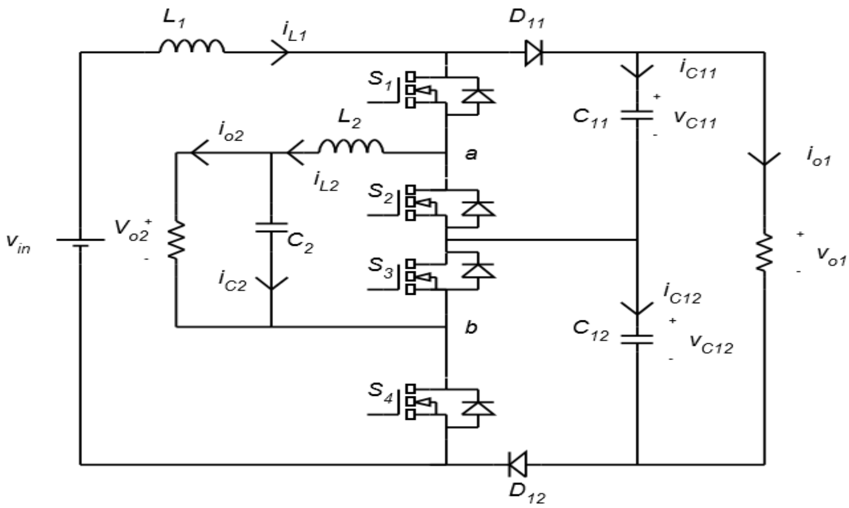

Fig-10: Three-leveldualoutputconverter

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a) Advantages

- Reducedvoltagestressonswitches&diodes
- Reducedpassivecomponentssize.
- Improvesefficiency

b) Disadvantages

- Fourpowerswitchesincreasethemanufacturingcost.
- Notsuitableforlowpowerapplications.

IX. SINGLEINPUTTHREEOUTPUTBASEDNONISOLATEDCONVERTER

In [11], a boost DC/DC converter with three outputs powered from a single source that is capable for expansion is discussed. Adiodeinductorcapacitorunitanddiodecapacitorunitisincludedtogetincreasedvoltageconversionratios. This converter uses the principle of switched capacitor and is preferable for RE conversion type systems like PV & FC. Becauseoftheavailabilityofthreeoutputsitmayalsofinduseinportableequipmentthatneedhighvoltageconversions. The expandable architecture enables in providing loads with different current and voltage ranges & with high frequencies and not preselecting wide duty cycles it secures high voltage gains. Converter does not use any coupled inductorortransformer. Ithassimpleswitchingpatterns&withtwoswitchesgoingON&OFFsimultaneously.

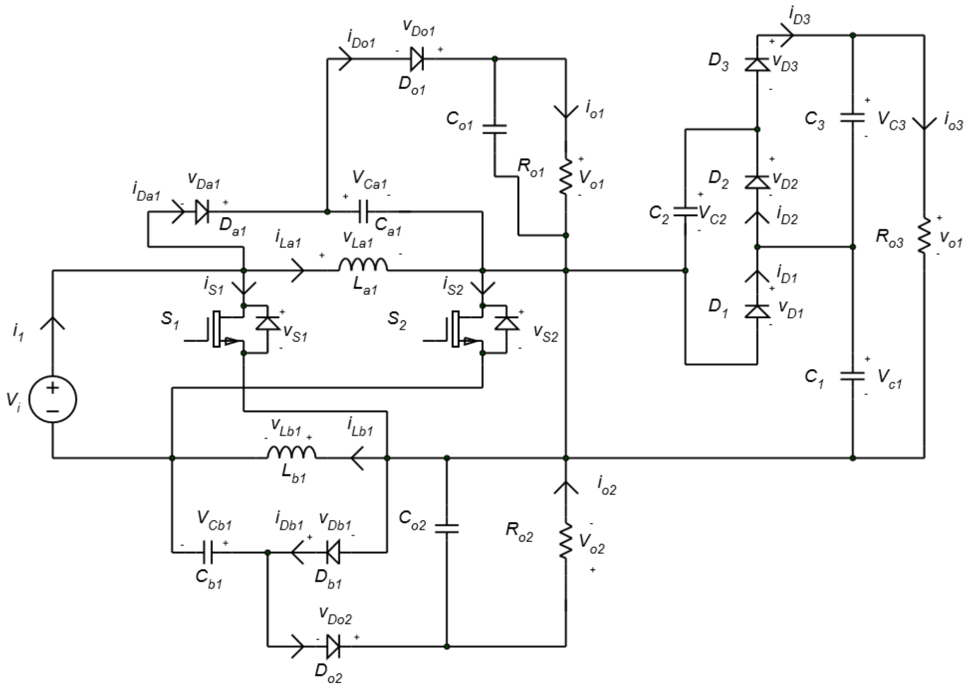

Fig-11: Singleinputthreeoutputnonisolatedconverter

a) Advantages

- Finduseinportableelements,FC,PVetc.whichwanthighvoltagegainratios.
- Without usinglarger values ofdutycycles nor byimplementinga transformer/coupled inductor itoffershigh gain.

b) Disadvantages

- Morenumberofpassivecomponentslikeinductors,diodes&capacitorsareused.
- Voltagegainisverymuchsensitivetoparasiticparametershere.

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X. SINGLEINPUTTRIPLEOUTPUTDC-DCCONVERTER

In [12], a DC/DC based converter consisting of three outputs attained by a single input is introduced as demonstrated in Figure 12. It is having soft-switching technique and can be implemented for high boost applications that need more than one output. Generally, more output with only a single input power is needed for RE or EV. Here the circuit can be powered by a low volt input source like solar. When operating under high step-up state, the converter offers larger voltage conversion ratio so that it can sustain the high volt DC bus for the usage of DC/AC inverters purpose. Here a coupled inductor is designed with low number of turn ratios to produce high voltage gain. An auxiliary inductor is incorporated to indirectly adjust the voltage available at auxiliary output section. Because of VC & ZCS techniques adopted here it favors in getting high efficiency power conversion ratios with three different voltage outputs.

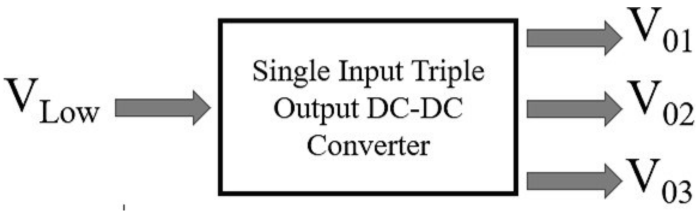

Fig-12: Blockdiagram

The system architecture for this converter topology is in figure 13. Symbols that are used for representation is as follows, in figure 14 low voltage side circuit i.e.; LVSC consist of S_1 which is a low volt switch, L_p implies the primary sides winding of the coupled inductor T_r used here, & V_{Low} denotes the low voltage input provided to the circuit. Turn on/off of S_1 will draw/release energy to L_s which implies the secondary winding of T_r. D_1 is the clamped diode, C_1 the corresponding clamped capacitor, C_{O3} implies the middle voltage"s filter capacitor and finally V_{O3} which is the middle voltage output section. Clamped section protects S_1 by absorbing energy at primary-side"s leakage inductor i.e.; L_k & release the energy to C_2 & V_{O3} which is middle-voltage capacitor & middle-voltage output section. C_2, D_2, L_s indicates the middle voltage capacitor, middle voltage balanced diode & secondary-side winding of T_r that forms the middle voltage balanced circuit.

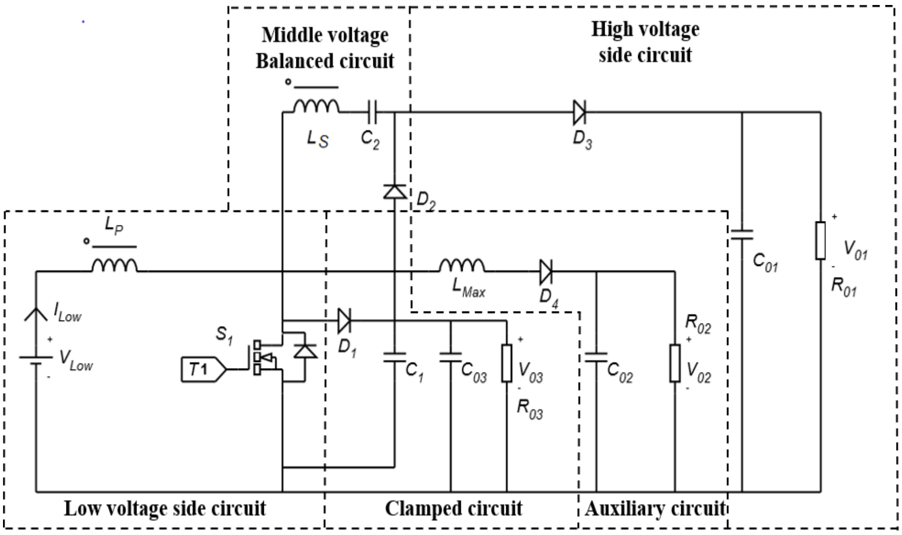

Fig-13: Circuitdiagram

The middle voltage section consumes energy at the C_1 & C_{O3} for stepping up the voltage gain ratio & offers energy to V_{O1}. Then, the HVSC i.e.; high voltage side incorporates D_3, C_{O1} & V_{O1} which indicates the high volt diode, filter capacitor with high voltage & high volt DC bus side. This side of the circuit gives energy to V_{O1} (high voltage side) through D_3. Finally the auxiliary circuit which incorporates an auxiliary inductor named as L_{aux}, an auxiliary diode termed as D_4, its corresponding auxiliary filter capacitor denoted by C_{O2}, & the auxiliary source output side named as V_{O2}. This section charges the auxiliary sources for external components usage. V_{Low} implies the voltage, I_{Low} implies the current of input source at LVSC. The equivalent loads for V_{O1}, V_{O2}, & V_{O3} is denoted by R_{O1}, R_{O2}, & R_{O3} respectively. S_1 is triggered by the driving signal T_1.

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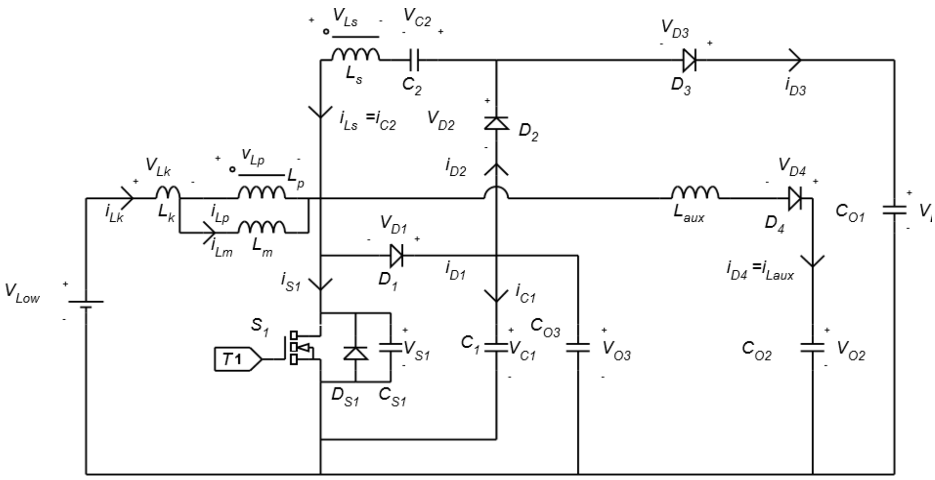

Fig-14: Equivalentcircuit

a) Advantages

- Highvoltagegain
- Onepowerswitchconfiguration
- Highefficiency

b) Disadvantage

- Highdutycycle
- To get more regulated outputs three winding coupled inductor along with an active switch must be incorporated.

Table-1: Comparisonoftheabovediscussedtopologies

Paper	Input Voltage	Output Voltage	Voltage Gain	Duty Cycle	Switching Frequency	Efficiency	No.of Power Switches
[4]	42V	V_1=400V; V_2=15V	G_{V1}=9.5, G_{V2}=0.35	0.7,0.4	30KHz	93%	6
[5]	24V	V_1:200V; V_2:58V	G_{V1}=8.33, G_{V2}=2.4	0.7	20kHz	94%	4
[6]	10V	V_1:200V; V_2:28V V_3:14V	G_{V1}=10, G_{V2}=2.8, G_{V3}=1.4	0.6	25kHz	95%	3
[7]	10V	V_1:180V; V_2:28V	G_{V1}=10, G_{V2}=2.8,	0.65	20kHz	95%	1
[8]	12V	V_1:18V; V_2:6V	G_{V1}=1.5, G_{V2}=0.5,	0.7,0.3	25kHz	90%	2

[9]	30V	V_1:230V; V_2:70V	G_{V1}=7.66, G_{V2}=2.33,	0.3	30kHz	92%	4
[10]	60V	V_1:125V; V_2:36V	G_{V1}=2.083, G_{V2}=1.667,	0.6,0.4	20kHz	95%	2
[11]	40V	V_1:200V; V_2:100V" V_3:360V	G_{V1}=5, G_{V2}=2.5 G_{v3}:9	0.6	20kHz	95%	4
[12]	12V	V_1:200V; V_2:25~30 V_3;40V	G_{V1}=16.67, G_{V2}=2.083, G_{v3}:3.33	0.7	50kHz	96%	1

XI. CONCLUSION

In this paper, a study on various configurations of DC-DC multiport converter with single input and multiple outputs is done. Applications that demand more than one output at a time can be fed from a multiport DC-DC converter so that it avoids the situation of using more converters for the same purpose thus making the system more compact and reliable. Because, as the number of inputs increases it accounts for the complexity of the system and also contributes to the increase in the overall cost of the system. The controlling part also become more difficult as the number of inputs increases. Multiport non-isolated DC-DC converters are much better than multiport isolated DC-DC converters because isolated type converters are bulky in nature due to the presence of transformers in it, it effects the overall cost and size of the converter to a great extent. Isolated converters have high voltage gain due to utilizing transformers with large turn"s ratio. However, they have a low conversion efficiency, poor performance due to leakage inductance. They also causes more power losses in the system due to the utilization of large turn"s ratio. Increased environmental problems such as global warming & climate changes in the recent years enhanced the demand for renewable energy sources. The renewable energy sources like PV & fuel cell generally want large step up DC-DC conversions in their output section to increase & regulate their output voltage. Generally, converters with only one input source & multiple output is required for applications like RES or EV. The important features of such converters are large voltage gain, high efficiency & low voltage stress on components. Switched inductor & switched capacitor techniques have been utilized widely to pursue high voltage gain but in switched inductor type converter, voltage stress among components is so high & in the switched capacitor topologies, the high current stress on semiconductors is the major problem. So to full fill the need of high voltage gain with single input, a coupled inductor based topology can be implemented by regulating the turn"s ratio. However, leakage inductance energy induce large voltage spikes on the main switch & decreases the overall efficiency. By introducing a passive clamping circuitry, the coupled inductors leakage inductances can be recycled.

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