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Advanced Dual Boost Inverter with High Voltage Gain DC to DC topology for PV Applications

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Abstract: ***A novel dual boost inverter with high voltage gain DC to DC converter for PV system application is analyzed in this paper. This new topology comprises of modified Dickson charge pump based voltage multiplier circuit at the front end and dual boost inverter on its next end. The notable advantages of this proposed converter circuits are boosting the DC voltage levels and inversion of DC to AC with a cost effective structure. The output of afundamental full-bridge inverter always appearsto belessthantheDCvoltageinput.Inordertoresolvethisissue,DCchopperisaddedat the front end of the converter to boost the AC voltage comparatively greater than the DC input Voltage. The blend of front end chopper and inverter bestows to a two-stage power conversion process. The conventional boost inverter has drawbacks like poor efficiency,discontinuouscurrentoperation,requirementoflargecapacitors,largeduty cycle and EMI issues. In this paper, the combination of the modified Dickson charge controller with dual boot inverter is proposed to acquire benefits like compact circuit structure, reduction in number of circuit components with boosting capability. The conventionalfullcyclemodulationschemeinthedualboostinverterleadstooperation of power devices at the higher frequency ranges through the full cycle. The voltage/current stress across the switching devices sequentially increases the losses associated with the circuit. So HCM modulation scheme is proposed to reduce the switching stress and switching losses. Furthermore, in order to address the current circulation losses, the clamping switches are added with the DBI inverter. The Dual boost inverter with modified Dickson charge voltage multiplier circuits are simulated andthehardwareprototypemodelisalsoconstructedtovalidatethesimulationresults.***

Keywords: ModifiedDicksonchargepump,Dualboostinverter,interleavedboostconverter Voltage Multipliers, Half cycle modulation, Clamp switch

1. INTRODUCTION

Energy playsan crucialrole to ensure the quality of life and to support all otherprogressof our nation. In the recent years, the consumption of energy has amplified and hence resulted in a huge demand. The renewable energy resources are playing a significant role to address the ever demanding energy needs. The Power generation processes using the traditional sources like coal and oil will increase the greenhouse effect and impact the environment. The deficiency in energy generation process and pollution issues can be considered as a main burden for growth of Industries. These concerns make the government entities, researchers, investors and other stack holders to focus more on the clean energy resources.

The right utilization of renewable energy resources is considered as one of key policy to reduce the dependence on fossil fuels and emissions of GHGs. The photovoltaic (PV) can be considered as a unique resource due to its reliability, sustainability, maintenance free and cost effectiveness .The voltage generated by the renewable energy resources like PV panels will be in the nature of DC voltage. Therefore it needs a double stage conversion process, at the first DC to DCconversiontoboostup theDCvoltages andtheninversion process toconvert theDCintoAC.

DC-DC converter models and inverters have fascinated the interest of numerous people due to its proficiency of converting the voltage levels.

2. EXISTINGBOOSTCONVETERANDINVETERTOPLOLOGIES

Some of the conventional boost converters, voltage-doublers, multiplier circuits, charge pump circuits and inverter topologies are discussed in this section.

2.1. Traditionalboostconverter

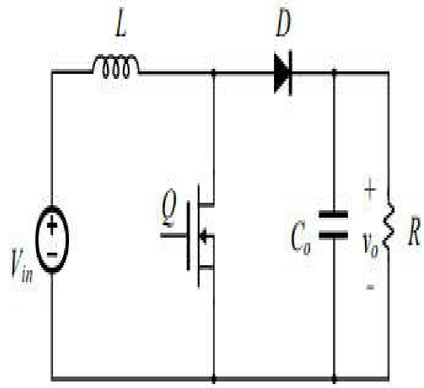

Figure1.1Traditionalboostconverters

The requirement to change an input DC voltage into a variable DC voltage is achieved via adopting the boost converter. It can be considered as an equivalent of transformer, in which boosting of AC is obtained. Simple boost converter circuit is shown in Figure 1.1. Vo= Vin (1−d) is used to find the output voltage of the boost converter.Here d is Duty cycle parameter. The key element of the circuit is inductor, but the physical size of the inductor is huge, which makes issue while integrating it in the circuit. The basic converter is operated at higher duty cycle values leads to voltage stress, switching losses and low efficiency.

2.2. CascadedandStackedBoostConverters

Theswitchesmustbeoperatedatgreaterdutycyclesinordertomaximiseefficiency. Switching losses are directly proportional to the operating duty cycle. So to improve voltage gain, the boost converters are connected in cascaded manner termed as stacked boost converters. Theimpact of conventional boost converters like high switching stress and high switching loss due to highdutyratiodonotexistinthiscascadedconnection.Incaseofanidealcascadedboost converter, the voltage gain will be computed using the equation Vo= Vin (1− d)2. Overall voltage gain is the product of gains of individual boost converters. Hstack= η1*η2.If m number of conventionalboostconvertersareconnectedincascadedmanner,thentheoverallvoltagegain computed as Vo= Vin (1− d)m. The multiple power processing stages in the cascaded connection in turn results inefficiency reduction.

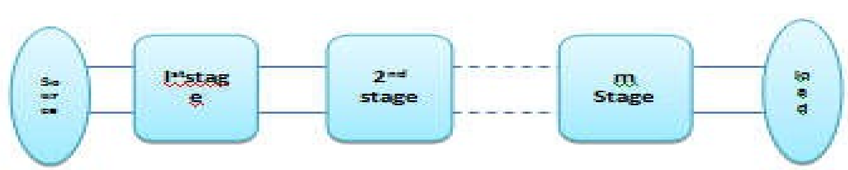

Figure1.2Cascaded/stackedboostconverters

2.3. Voltagemultipliers

The voltage multiplier circuits constructed by the ladder network connection. The Voltage Multiplier Circuit (VMC) is categorized as Dickson charge and Cockcroft-Walton VMC based on methods of capacitors connection. It's perceived from the circuit diagram of Dickson Voltage Multiplier,thecapacitorsnegativeendsareconnectedtoPhaseAandPhaseB.Differencebetween the Cockcroft-Walton VMC and Dickson Voltage Multiplier lies in the connection the capacitors. Unlike DicksonVoltage Multiplier, negative endofodd capacitor andpositive endofthe previous odd capacitors are connected together and similarly, negative end of even capacitor and positive end of the previous even capacitors are connected together in the Cockcroft-Walton VMC. Higher voltage gain, small voltage stress across the circuit elements, compactness are the major advantages ofvoltage multipliers.These converters are lighter and cheaper. Thismodel eliminates the need for a transformer with heavy core and insulation to boost voltage levels.

2.4. DicksonchargeMultipliers

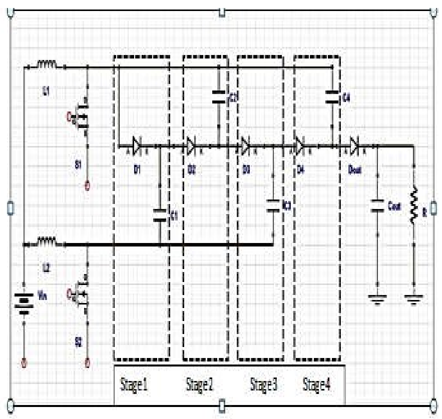

Figure1.3Dicksonchargepump-High VoltageDC-DCconverter

DCsystemhasnumerousbenefitsoveranACdistributionsystemlikehigherefficiencyand reliability, reduced installation costs, easy integration with renewable energy resources and free from synchronization issues. The output of the PV panels is DC and it can be directly applied tothe DC loads without any conversion stage. But if the requirement of DC voltages is higher, then there is a need for high-voltage-gain converters.

Additiontothat,tofeed theoutputofSolarpaneltoACloads,certainlyapowerconversion stageisessentialinordertoconvertDCtoAC.Theprocessofboostingthevoltagefrom20V/40V DC to 400 V DC is a complex process. If simple boost and buck-boost converters are used, the switches must be operated under high duty ratio situations, resulting in high stress and lower efficiency. In order to address these issues, the two converters can be connected in cascaded mode.Isolated topologies like fly back converter, half and full-bridge converter have intermittent input currents and henceforth need bulky input capacitors. All these issues will addressed in the Dickson charge controller circuits.

The Dickson charge type voltage Multiplier circuit is shown in the fig(1.3). The input voltage will be multiplied at the end of each of the capacitor section. If the input voltage is considered as N level, then at the each stage, the output voltage obtained is in the order of 2N,4N,6N and 8N in a four stage multiplier circuit.

2.4.Boostinverter:Invertercoupledwithchopper

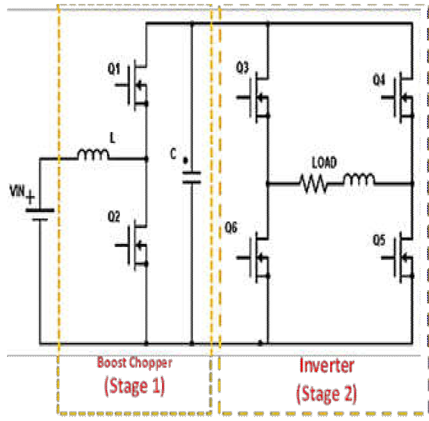

Figure1.4DualstageboostinverterwithChopperatfrontend

Generally,theoutputvoltageofsinglephasevoltagesourceinverterisfoundlesserthanthe DCinputvoltage.Henceitisnotadoptedinhighlevelapplications.Thereforecascadedtopologies and multilevel topologies are used the boost the level of output voltage. To increase front end DC voltage level, an additional DC–DC conversion stage is implemented in addition with an inverter. Therefore boost inverter as per fig 1.4 has two stage conversion levels, i.e. DC-DC boosting and DC to AC conversion by an inverterwhich yields to circuit complexity. More number of switches in association with more switching loss is the main concern in this category of converter. Hence a DBI with modified Dickson charge converter has been proposed in this paper with less power devices and improved boosting ability.

3. PROPOSEDSYSTEM

3.1. ModifiedDicksonChargePumpVoltageMultiplier

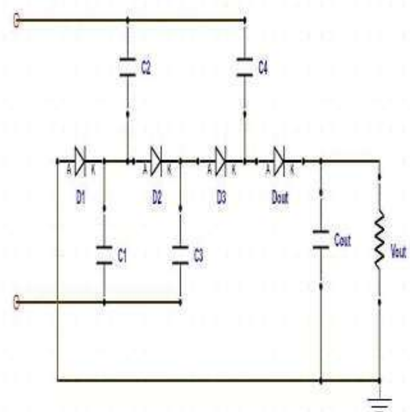

Figure3.1.ModifiedDicksonCharge Pump

The topology with minimum components, higher voltage gain, compactness and higher power density are the essential parameters of an ideal topology. Meanwhile, designing a new powerelectronicsconverter,variousparameterslikenoofswitches,switchingstressandloss,High power density, Heat dissipation, harmonics/ripples, efficiency with cost will be considered as prominent data's. Modified Dickson charge controller has reduced number of components and the size of capacitor is also reduced due to reduction in the voltage stress.

Themainbenefitsofthemodifiedconverterincludecontinuousoutputcurrentandreducedvoltage stressacrossswitches,making the modified Dickson chargeconverterideally suited forrenewable energy applications, particularly for increasing the DC voltage outputs of solar panels. The identicalcurrentstressacrosstheinductorsandswitchesmakesthecomponentselectionprocessof this converter as a simpler work. Modified Dickson charge pump circuit as shown in Fig.3.1. The voltage levels across the capacitors are moderately low. The High gain boost converter topology using the modified Dickson charge pump is shown in the fig 3.2.

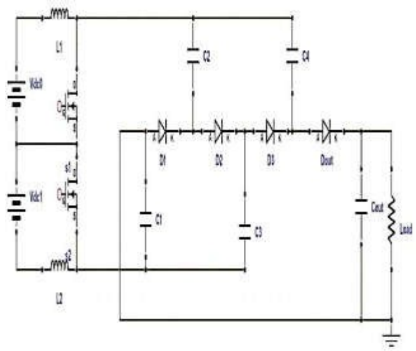

Figure3.2.HighgainDctoDCconverterwithModifiedDicksonChargePump

4. MODESOFOPERATION

4.1 ModeI:

In thismode1Fig4.1,switchesQ1andQ2ofthetwophaseinterleavedboostconverterare keptatONstate. Vdco and Vdc1willchargethe inductorsL1 and L2respectively and the inductor currents iL1 and iL2will starts to raise linearly. Diodes D1, D2, D3 and Dout of the modified Dickson charge converter unit remains at reverse biased condition and hence they are at OFF mode. The voltages across the modified Dickson charge controller capacitors remain as the same. Because the Dout diode is likewise turned off, the load is supplied by the output capacitors.

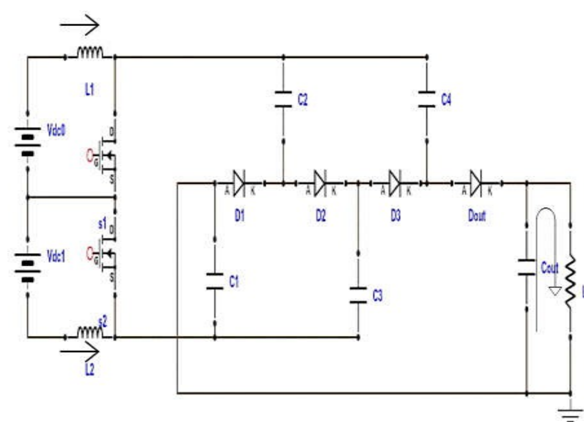

Figure4.1ModeIoperationofModifiedDicksonchargepump

4.2 ModeII:

Considering the mode 2 operation, Q1 off and Q2 maintained in the ON state. D1 and D3 reversebiased condition andhence theyareat OFF state. The othertwo diodes D2andDoutare in forward bias condition and hence at the ON state. The current iL1flows through capacitorC2to charge it. The diode D2 is under forward biased condition, the current iL1 will also flows through the capacitor C3to charge it. Remaining current of iL1 will flows through the capacitor C4 and C1will starts to charge the output capacitor Cout and load.

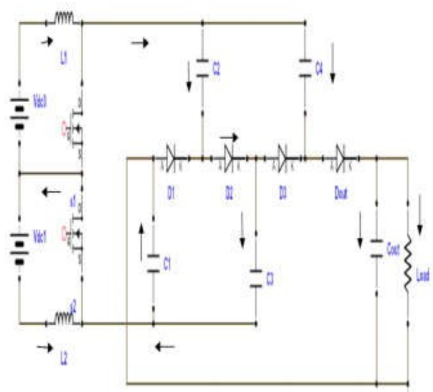

Figure4.2ModeIIoperationofModifiedDicksonchargepump

4.3 ModeIII:

This mode is the reversal operation of the mode II. (i.e.) Q1 is turned ON and Q2 off. D1 and D3 are under ON . Diodes D2 and Dout are under reverse bias condition. As the switch Q1 turned ON, Inductor current iL2flowvia C1, C2, C3, and C4.The Capacitors C1 and C4 are under charging process while C2 and C3areatdischargingprocess.

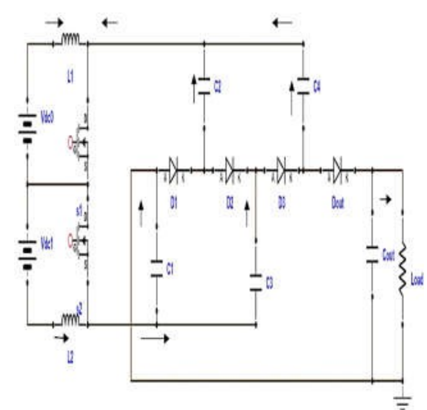

Figure4.3ModeIIIoperationofModifiedDicksonchargepump

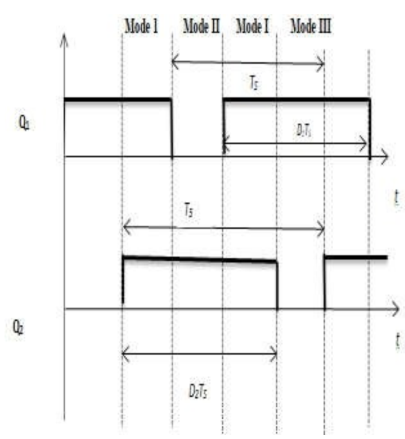

Figure4.4SwitchingsignalsfortheswitchesQ1&Q2ofmodifiedDickson charge converter

In this mode III, the output capacitors feeling the load. Switching sequence of Q1 and Q2 are indicated in the Figure 4.4.

5. DUALBOOSTINVERTER

5.1 DualboostinverterwithHCMScheme

Implementationoftraditionalmodulationschemes(fullcyclemodulation)makesthepower switches to operate at higher frequency ranges. It will considerably increase the conduction and switching losses. Hence, the adoptionofnew modulation schemes isrequired to improvethe work efficacy of the circuit. The half cycle modulation (HCM) strategy with Dual boost inverter is analyzed to reduce the above said issue. In addition to that, the current circulation losses will be reducedwiththeinclusionoftwoclampingswitches.Theadditionofclampingswitchprovidesthe bypass path for the inductor current and consequently the losses caused by circulation current significantlyreduced.Hence,thisimprovedtopologyofDBIwithclampingswitcheswillresultsin higher efficiency with low switching stress across its elements. The switching signal generated with the half cycle modulation is shown in figure 5.1.

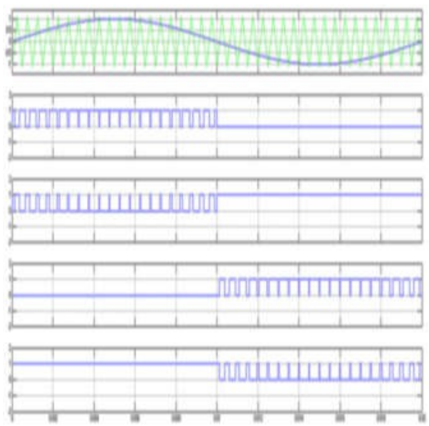

Figure.5.1HCMschemeoftheDBIwithoutclampingswitches

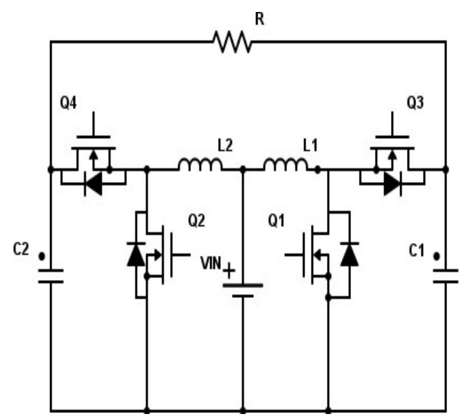

Figure.5.2Dualboostinverterwithoutclampingswitches

Dualboostcircuitdiagramofinverterwithoutclampingswitchtopologyisshowninfig 5.2.It constructed with four power switches, indicated asQ1, Q2,Q3 and Q4,Voltages measured acrossC1, C2capacitorsare taken as V0, DC voltage at supply side represented as VIN,Vm is the outputACvoltage.Forthedurationofthepositivehalfcycle,Q1andQ3willturnedONandduring the next half cycle periodQ2and Q4 will turned on in complementary mode.

5.2 OperatingmodesofDBIwithoutClampingSwitches

a) Mode 1 [t0, t1]: At t0, Q1 and Q4turned on, input voltage is applied and L1starts its charging process through the input current. Load current i0 will flow through Q4(D4) to Vin, which supplied by C1 .
b) Mode 2 [t1, t2]: The period is dead time. At t1, Q1, Q2, Q3are turned off, Q4is turned on, the current iL1flow through D3or D1 (according to the direction of current), Load current i0 will flow through Q4(D4) to Vin.
c) Mode 3 [t2, t3]: Att2, Q3isturned on, iL1flow through Q3(D3). Load current i0flow through Q4 (D4) to Vin.
d) Mode 4 [t3, t4]: This is also a dead time period, and its operation is similar to mode 2. Atthis period, the measured voltage is negative.
e) Mode 5 [t6, t7]: At t6, Q2, Q3are turned on, the input voltage is applied and the input current charges L2. Load current i0will flow through Q3 (D3) to Vin, which supplied by C2
f) Mode6[t7,t8]:Thisdurationisalsodeadtime.Atinstantt7,Q1,Q2,Q4areturnedoff,Q3is turned on, iL2flow through D4/ D2. Load current i0will flow through Q3(D3) to Vin.

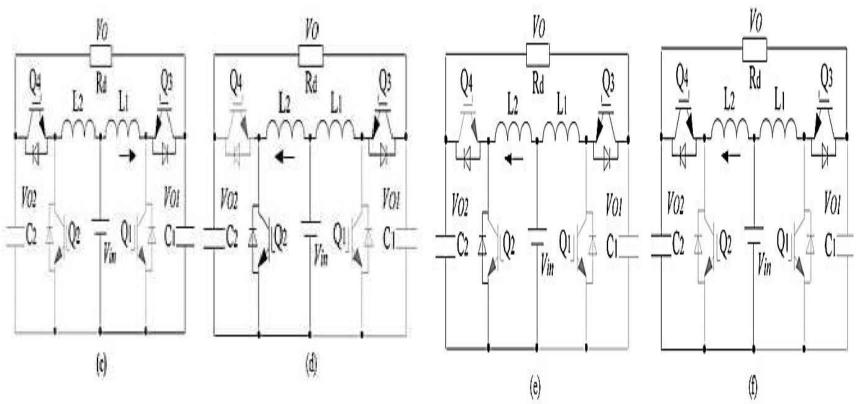

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Figure.5.3Modesofoperationatvariousinstances(a)[t0,t1],(b)[t1,t2]or[t3,t4], (c)[t2,t3],(d)[t6,t7],(e)[t7,t8]or[t9,t10]and(f)[t8,t9].

5.3 Dualboostinverterwithclampingswitches

Operation of dual boost inverter without clamping switch is explained under the Section B. Theadaptionofhalfcarriermodulationschemeresultedwiththereductioninswitchinglosses.But the Current circulation issues with its associated losses still persists in the proposed converter circuit. In order to address this issue, a new topology with clamp devices is suggested. In this topology, only one inductor is used for boosting operation and the at the output side, clamping switch is associated to clamp the input voltage Vin. The operating frequency of the clamping switches is maintained as equivalent to the line frequency, which gives the advantage of lower voltage stress.

CosteffectiveswitcheslikeMOSFETcanbeemployedinthecircuitincomparisonwiththe IGBT in the identical condition. The circuit of the proposedDBI with clampingswitches is shown in Fig 5.4.

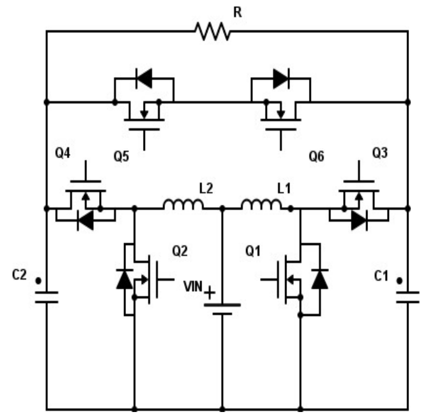

Figure.5.4Dualboostinverterwithclampingswitches

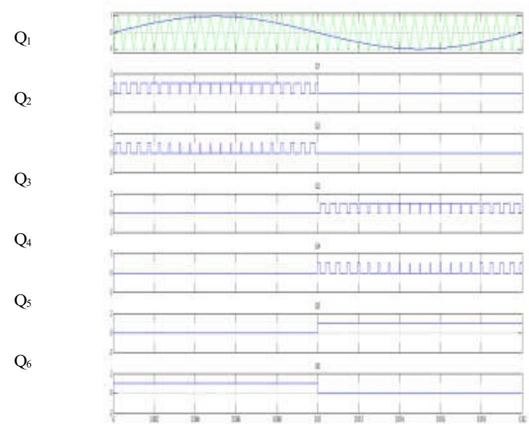

Figure5.6HCMSchemeofDBIwithclampingswitches

5.4 ModesofOperationofDBIwithClampingSwitches

a) Mode 1 [t_0, t_1]: At t_0, Q_1, $Q_4$is switched on; the input voltage is supplied to $L_1$and the input current flows and charges the Inductor L_1.Load current $i_0$will flow through $Q_4(D_4)$ to V_{in}, which is supplied by $C_{1.}$

b) Mode 2 [t_1, t_2]: The period is dead time. At $t_1$instant, Q_1, Q_2, $Q_3$are switched off and $Q_4$is switched on, the current i_{L1}flows through D_3or D_1, as shown in Fig. 3.11(b). Now the Load current $i_0$direction is via $Q_4(D_4)$ to V_{in}.

c) Mode3[t_2,t_3]:Att$_2$,Q_3isturnedon,i_{L1}flowthrough$Q_3(D_3)$.Loadcurrent$i_0$flowthrough$Q_4(D_4)$ to V_{in}..

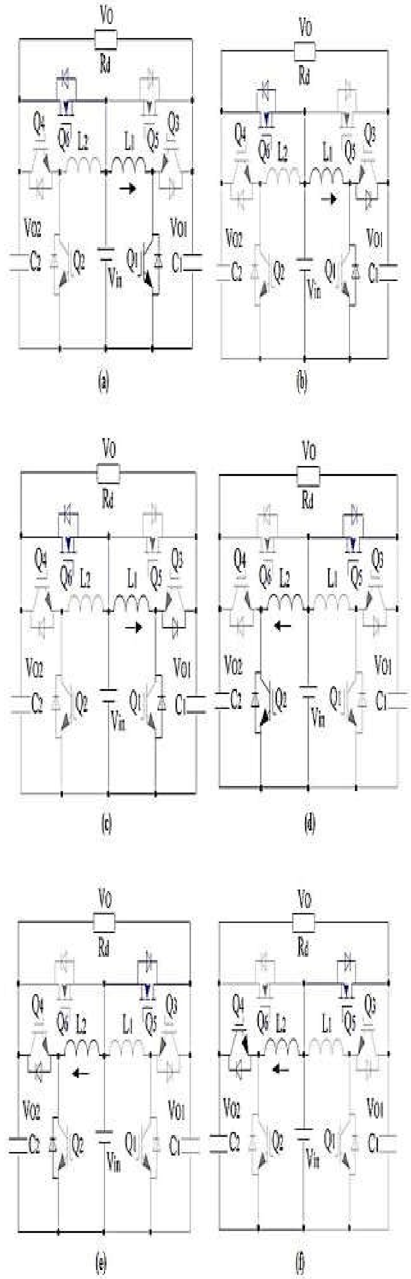

Fig5.5Equivalentcircuitsofswitchingmodes(a)[t_0,t_1],(b)[t_1,t_2]or[t_3,t_4],(c)[t_2, t_3], (d) [t_6, t_7], (e) [t_7, t_8] or [t_9, t_{10}] and (f) [t_8, t_9].

Mode 7 [t8, t9]: Att8, Q4isturned on,iL2flow through Q4(D4).Now the Load current i0direction is via Q3 (D3) to Vin.

Mode8[t9,t10]:Thisfinalmodeisalsodeadtimeperiod,withsimilartomode6

Mode 4 [t_3, t_4]: This mode 4 is also called as dead time period and the workings process is samelike Mode 2 with negative output voltage.

Mode 5 [t_6, t_7]: At t_6, Q_2, $Q_3$are switched on, the input voltage and the input current charges theinductor L_2. Load current $i_0$will flow through Q_3 (D_3) to V_{in}, which supplied by C_2

Mode 6 [t_7, t_8]: It is again a dead time. At t_7, Q_1, Q_2, $Q_4$are turned off, $Q_3$is turned on, the current i_{L2}flows through D_4or D_2.Load current $i_0$will flow through Q_3(D_3) to V_{in}.

Mode 7 [t_8, t_9]: At t_8, $Q_4$is turned on, i_{L2}flow through Q_4(D_4). Load current $i_0$flow through Q_3(D_3) to V_{in}.
Mode8[t_9,t_{10}]:Thisperiodisalsodeadtimeperiodwithsimilaroperationasmode6.

5.5 Simulationparametersoftheproposedsystem

Table1:MatlabSimulationParametersofDBIWithoutandwithClampingSwitches

Parameters	Withoutclampingswitch	Withclampingswitch
Supplyvoltage	50V	50V
Outputvoltage	68V	105V
Inductor	500µH	500µH
Capacitor	20µF	20µF
InductiveLoad Parameter	-	5µH
CapacitiveLoadParameter	2700µF	2200µF
ResistiveLoadParameter	20Ω	20Ω
SinewaveFrequency	50Hz	50Hz
Carrierfrequency (Triangularwave)	20KHz	20KHz
DutyCycle	71%	71%
SwitchingTechnique	HCM	HCM

Table2:MatlabSimulationOfModifiedDicksonChargePump

Parameter	Description
InputVoltage	20V
OutputVoltage	400V
LoadResistance	800Ω
DutyCycleofSwitchesS1 and S2	80%
SwitchingFrequency	100kHz
ValueofL$_1$andL$_2$	100µH
VMCapacitor	60µF
OutputCapacitor	22µF

5.6.**Hardwareimplementationoftheproposed**

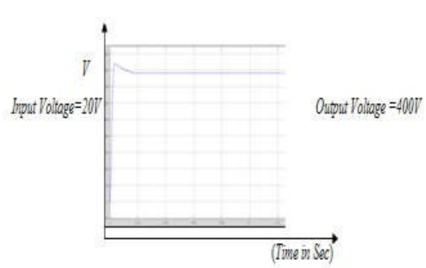

Figure5.6OutputVoltagewaveformofDicksonchargevoltagemultiplier unit system

Figure5.7HardwarePrototype

6. CONCLUSION

Thecombination of atwo-phase interleaved boostconverteratthefrontend and amodified Dickson charge pump voltage multiplier circuit at the rear end results in a new topology.DBI can be achieved as a one stage converter, which has advantages such as a simple structure, fewer components, and buck-boost capability. The suggested system employs HCM method, which causes power switches to operate at a high frequency for half of a cycle. To reduce current circulationlosses,anenhanced DBIarchitecturewithtwoclampingswitchesisalsoproposed. The DBI'smodulationmethodcausedalloftheswitchestooperateathighfrequencies.Thisresultedin significant voltage/current stress as well as high conduction and switching losses. The suggested half cycle modulation causes power switches to operate at high frequency for only half a cycle, reducing conduction and switching losses in power devices.

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