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High Gain Single Switch DC/DC Converter Adopting Switched Capacitor Cells for Standalone Applications

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ABSTRACT

Energy shortage and environmental contamination in the present scenario has increased the use of renewable energy sources.Among the renewable energy sources the photovoltaic cells plays a significant role in meeting the energy requirements. The problem associated with the PV cells are it produces low output voltage and thus a high step-up dc dc converter is essential to boost the low voltage of a PV to obtain high bus voltage for the downstream dc ac grid-connected inverter. The converter proposed here is a combination of two types of converters which has the advantages switched-capacitor (SC) converter to produce high voltage gain and excellent output regulation of a switching mode dc dc converter. The basic idea of a voltage multipliercircuit and regulation of switched mode dc - dc converter is adopted here.When the switch is turned on, the inductor is charged, and the capacitors are connected in series to supply the load, and the inductor releases energy to charge multiple capacitors in parallel when the switch is turned off whose voltages are controlled by a pulse width modulation technique. Thus a dc dc converter can be obtained with high voltage gain and good regulation.

Keywords: *High efficiency, high voltage gain, non isolated, switched capacitor (SC).*

I. INTRODUCTION

The traditional fossil energy such as coal, petroleum and natural gas are being used extensively to meet ever growing demand of energy has adversely affected the environment on a global scale, such as environmental pollution and greenhouse effect. Since traditional fossil energy is not renewable, there exists a contradiction between the fossil energy and global energy demand. So it is necessary replace the fossil energy with clean and renewable energy sources. Solar energy and hydrogen energy are promisingsources ,and photovoltaic (PV) and fuel cell power generation as the utilization method of the two new energy types have been applied on a large scale[1].

Renewable energy systems generate low output voltage, andthus, high step-up dc/dc converters have been widely employed in many renewable energy applications such fuel cells, wind power generation, and photovoltaic (PV) systems[2]. In a single-phase system , if the line voltage is 220 V, the bus voltage of the grid-connected inverter needs to be as high as 380 V. However, the output voltages of PV and fuel cells are generally ranged from 25 to 45 V, which are much lower than the bus voltage. Thus a dc/ dc converter with high voltage gin is needed to boost the output of renewable energy systems[3].

The boost converters are commonly used among the nonisolated converters for voltage step up. It can provide high step-up voltage gain, but with the penalty of an extreme duty ratio when the output voltage is much higher than that of input volatge[4]. Thus, the current ripple of the inductor and turnoff current of the power device are large, which results in large conduction loss, switching loss, and thus low efficiency. A high voltage gain can be easily obtained by cascading with another boost converter but it requires too many components which leads to high cost and low overall efficiency[5].

A boost converter with coupled inductors with appropriateturns ratio can effectively increase the voltage gain, but the presence of leakage inductors in coupled inductors would results in high component stress, low

conversion efficiency and high noise level. A snubber circuit can be used to absorb the energy stored in the leakage inductor. But , it increases the circuit complexity and leads to low efficiency.

The switched-capacitor (SC) converter can obtain a highvoltage gain, but the input current is pulsating, and the load and line regulation is poor. By incorporating the SC structureinto the switching-mode dcdc converters, the voltage gaincan be dramatically increased with an appropriate duty cyclewhile the voltage regulation is achieved.[7][8] The voltage gain of the SC converter is high, but the output voltage is not regulated. The output regulation of the non isolated switchingmode dcdc converter is excellent, but the voltage gain cannot be too high for achieving high efficiency[1]

This paper proposes a combination method of the SCconverter and the switching-mode dc dc converter. The basic approach is introducing multiple capacitors into the switchingmode dcdc converters. When the switch is off, the energy released from the inductor is used to charge the capacitors in parallel. When the switch is on, the capacitors are connected in series to supply the load. [1][2]Thus, the voltage gain isincreased, and the duty cycle is decreased, leading to small ripple current and turn off current of the switch, and high efficiency can be expected. Meanwhile, the voltages of the capacitors are well regulated thus achieving a tightly regulatedoutputvoltage.Inaddition,thenewconvertersproposedinthis papercanbeinfinitely extendedwhenanenormousvoltage gainisneeded.[6]

ADCtoACpowerinverter isneededtoconvert theDC voltagegatheredbyphotovoltaiccellsintoACvoltage.Sothe highgaindcdcconverterisconnected toasinglephasesine pwminverterinordertoobtainasinusoidaloutputwhichcan beappliedforgridconnected orindustrialapplications.The sinewaveinverters giveapuresinewaveoutput[9].They operateinnearperfectefficiency,maximizingtheoutput.Pulse WidthModulationistheprocessofvaryingthewidthofpulse or pulsesto control the output voltage of inverter[10].In SPWM,thewidthofeachpulseofapulsetrainisvaried inproportiontotheamplitudeofasinewaveevaluatedat thecentreofthesamepulse.Thesinewaveisconsidered as referencesignal, whilea triangularwave is treated as the carrierwave.Thefrequencyofreferencesignaldetermines theinverteroutputfrequency, anditspeakamplitude controls themodulation index.Forsinglephasesinewavegeneration, twoPWMpulsesareneeded.Thereference sinusoids ofthese twopulseshaveamutualphaseshiftof180degreeandboth ofthemareofsamefrequency[11]-[12].

II. SCCONFIGURATIONWITHINDUCTORENERGY STORAGECELL

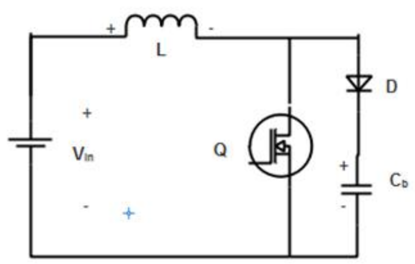

Fig. 1. SC structure with a single inductor energy storage cell in boost Configuration

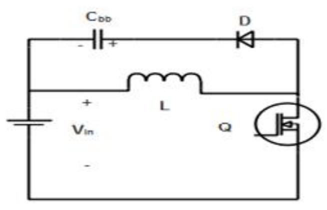

Fig.2.SCstructure withasingleinductor energystoragecellinbuckboost configuration

Itcanbeseenthatitiseffectivetoincreasethevoltage gainbychargingtheSCsinparallelanddischarging inseries. However, theoutputvoltageofthisstep-upSCconverter cannotberegulated, anditvarieswiththeinputvoltage.To solvetheproblem, Fig.1andFig.2showsaninductor energy storagecellthatisusedtochargetheSCs.WhenswitchQ ison,theinputvoltagesourcechargestheinductor.WhenQ isoff,theinductorchargestheSC.ThevoltageoftheSC canberegulated byadjusting thedutycycleofswitch.The circuitshowninFig.1issimilartoaboostconverter,whereas thecircuitshowninFig.2resembles abuck boost converter. Hereinafter, theSCiscalledtheboostcapacitorwhenitisin parallel withtheswitch, andtheSCiscalledthebuckboost capacitor whenitisinparallelwiththeinductor. Atsteady state,thevoltsecondrelationshipoftheinductorisgivenas

$$V_g D T_S = (V_{cb} - V_g)(1 - D_y) T_S = V_{cbb}(1 - D_y) T_S \quad (1)$$

whereV_{cb}andV_{cbb}arethevoltagesoftheboostcapacitor andthebuckboostcapacitor,respectively, andDyistheduty cycle.Then,V_{cb}andV_{cbb}canbederivedas

$$V_{cb} = (V_g / (1 - D_y) \quad (2)$$

$$V_{cbb} = V_g D_y / (1 - D_y) \quad (3)$$

II. OPERATINGPRINCIPLE

Thecircuitdiagramof theproposedconverteris shown inFig3.Itconsists ofasingleswitchS,aninductor L,two switchedcapacitorsC_1 andC_2,andfiltercapacitorC_f.The inputisgivenfromalowvoltage DCsourceiefroma photovoltaic cell.Theoperationisbasedonthechargingand dischargingoftheinductorandswitchedcapacitors.The high gainDCDCconverter feedingansinepwmbasedHbridge inverterisshowninfig.4Theworkingoftheconverterinvolves chargingof theinductorwhenswitchQ is ONandwhen switchisOFF,theseriesconnectionofcapacitorssupplies theloadand,inductor releases energytochargetheparallel connectionofcapacitors.

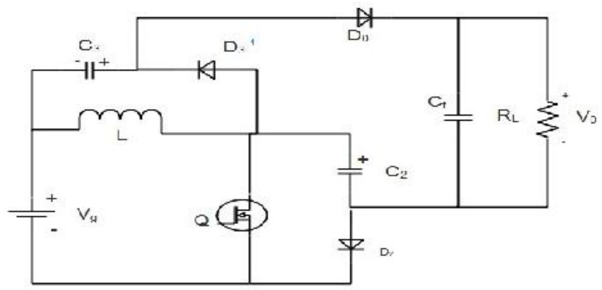

Fig.3.Proposedhighstepupconverterwithswitchedcapacitorcell

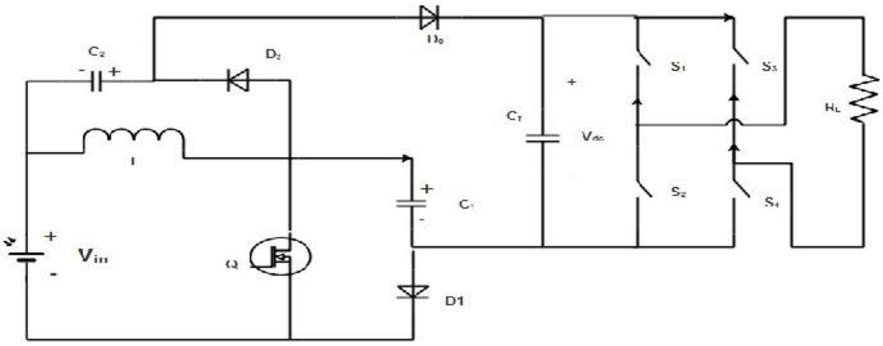

Fig.4.Proposedhighstepupconverterwithswitchedcapacitorcellfeeding a singlephasespwminverter

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1) Mode1:During thismode,switchQisturnedONand theinductor Lstartscharging fromtheinputvoltagesource. WhiletheC_1 andC_2 isinseries with voltagesource tosupply theloadasshowninfig.5.Herethecapacitor C_1 actsasboost capacitor.

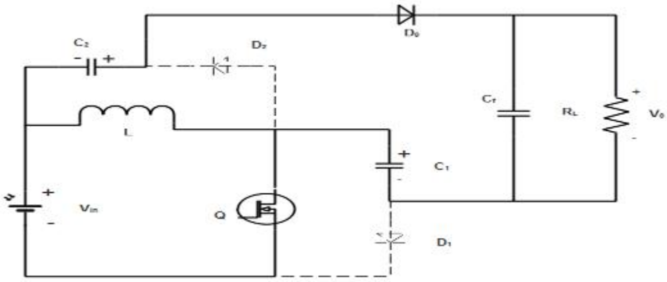

Fig.5.SwitchQisON

*2) Mode2:*Inthismode,SwitchQisturnedOFF,switched capacitors C_1 andC_2 arechargedbytheinductor whichare connectedin parallel and the load is supplied by C_f.The switched capacitor C_2 has buck boost operation which is showninfig.Inthisconverteroneoftheswitchedcapacitor

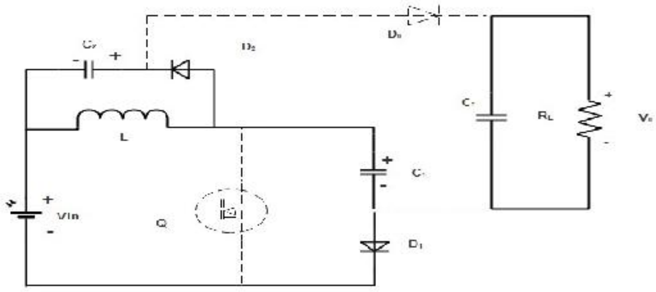

Fig.6.SwitchQisOFF

istheboostcapacitor andotheroneisabuckboostcapacitor. Soitcalledasatype1boostconverter orbuckboostbased converter.The highstepupconverterisfeedingasinepwm basedinverter toobtainanACvoltage inordertoobtainthebus voltageofgridconnectedsystem.

IV. ANALYSISOFTHECONVERTER

*3)Voltagegain:*ThevoltagegainMoftheconverterwhen theswitchQcanbeexpressedas

$$M = V_o/V_{in} = D_y/(1-D_y)+D_y/(1-D_y)+1 \quad (4)$$

$$M = 2/(1-D_y) \quad (5)$$

so the voltage equation of the converter is

$$V_o = 2V_{in}/(1 - D_y) \quad (6)$$

Where,

V_{in}- is the input voltage in V

$V_o$is the output voltage in V

D_y isthedutycycle

4) Voltage across switched capacitors: The voltage across the capacitor $C1$ and $C2$ can be obtained from the mode 1 and mode 2 respectively

$$Vc1 = Vin/(1 - Dy) \quad (7)$$

$$Vc2 = Vin * Dy/(1 - Dy) \quad (8)$$

5)InductorDesign: Theinductorisdesignedtolimitthe maximum currentrippleto20percentage ofthemaximum averageinductorcurrent.Sotheinductordesigncanbederived as

$$i_L = V_g D_y T_S / L = V_O (1 - D_y) D_y T_S / 2L \quad (9)$$

where,

I_O-istheoutputcurrentinA

i_L-istheripplecurrentinA

T_S-istheTimeins

*6)Designofswitchedcapacitors:*TheSCisconsidered as voltagesourcehere.So,thereexistsasmallvoltageripple at theswitching frequency onthecapacitor. Whentheswitchis on,thesumofvoltagesofC1andC2andthevoltagesource isslightlylargerthantheoutputvoltage.Then,C1andC2 andthevoltage sourceareinseriestosupplytheload.Hence, thevoltagerippleshouldbelimitedtoasmallrangeincase oftoolargecurrent. Astheaverage currentofthebranchof filter capacitorCfiszero,theaveragecurrentthatC2andC3 outputtotheloadwhentheswitchconductsisIo,whereIo istheloadcurrent.Then,thevoltageripplesare

$$V_{c1} = I_O T_S / C_1 \quad (10)$$

$$V_{c2} = I_O T_S / C_2 \quad (11)$$

7) Output Filter Capacitor Cf: Considering the high step up dcdc converter is cascaded with a single-phase inverter, the voltage ripple is limited to 1 percentage of the output voltage. Thus, the capacitance is

$$Cf = Po = 2fVoVo \quad (12)$$

where,

Po - is the output power of the converter in W

f - is the line frequency in Hz

V. SIMULATIONRESULTS

The suggested high gain step up DC - DC converter adoptingswitchingcapacitor cellhasbeensimulated using MATLABsoftware.Thesimulationparametersareselected as:

$P_O = 100W$

$V_i = 25 - 45V$;

$C_1 = C_2 = 3.46uF$; $C_f = 220uF$

$L_1 = L_2 = 2.145mH$; $R = 1444\Omega$

Switchingfrequency, $f = 20KHz$

Thesimulinkmodelofclosedloopoperationofthehigh stepupdcdcconverterisshowninfig.7. Inordertostabilise theoutputvoltageoftheconverterPIcontrolisused.

Thesimulation resultforclosedloopoperationofthe converterisshowninfig.8.The desiredoutputvoltageasper thevoltagegainequationoftheconverter is380V.Fromthe simulation

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theoutputvoltageobtainedisclosertothedesired valuethatis379.8Vwithanoutputcurrentof0.263Afora loadof1444ohm.

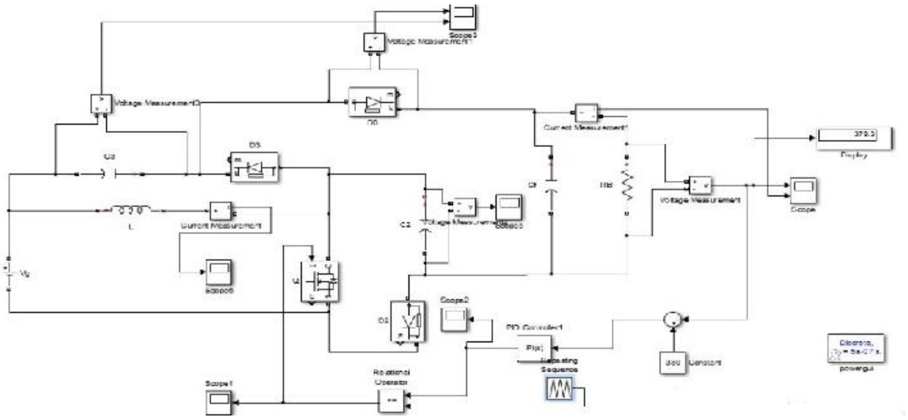

Fig.7.Simulinkmodelofclosedloopoperationofconverter

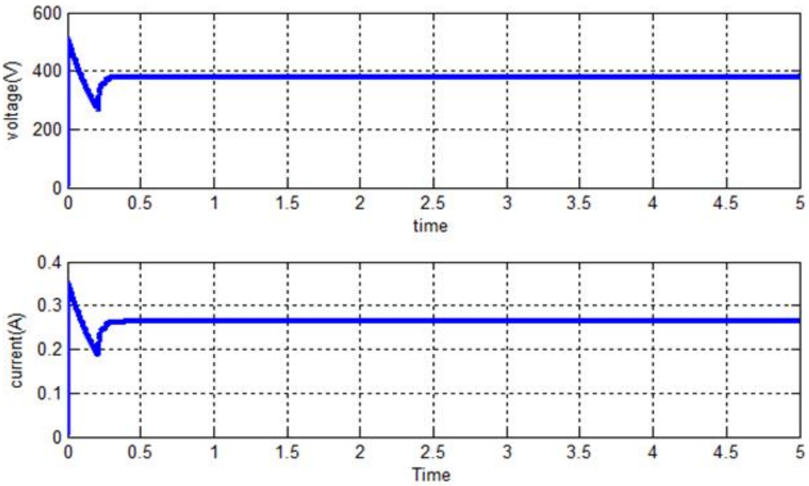

Fig.8.Simulationresultsofclosedloopoperationofconverter

Thesimulinkblockdiagramandsimulationresultoftheconverterfeedingansinglephaseinverteris showninfig.9.and fig.10.respectively.TheoutputoftheinvertercircuitisaPWM wave,withaswitchingfrequencyof20kHz.AnL-Cfilter is attachedparalleltotheload,whichattenuates thePWMand producespuresinewave.

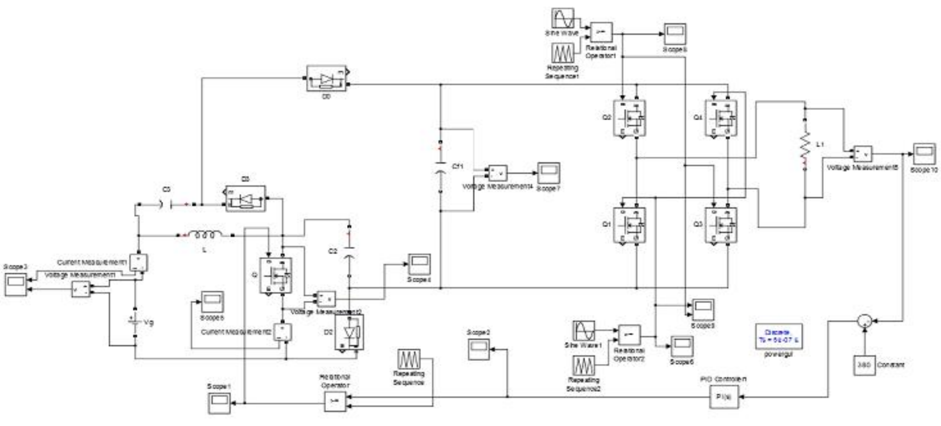

Fig.9.Simulinkmodelofclosedloopoperationofconverterwithsingle phasespwminverter

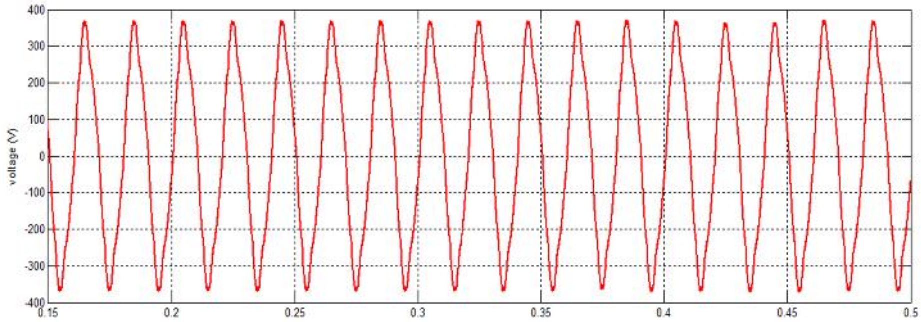

Fig.10.Simulationresultsofclosedloopoperationofconverterwithsingle phasespwminverter

VI. CONCLUSION

Themainobjectiveofthisprojectwastofind anefficient powerconversionsystemtousephotovoltaic energytomeet the increasingpowerdemandsof residentialand industrial sector.The operatingmodeofahighgainsingleswitchdcdc converter adoptinganswitched capacitor cellproposed inthis paperwassimulated andanalysed.Whentheswitchisturned off,theenergystoredintheinductor isreleased tochargethe multiplecapacitorsinparallelwhosevoltagesarecontrolled byapulsewidthmodulation technique;whentheswitchis turnedon,thecapacitors areinseriestosupplytheload.By incorporating asinglephaseinvertertothehighgaindcdc converterwithswitchedcapacitorcellsahighvoltagegain canbeobtainedtofeedthegridconnectedsystem.

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