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Semi Active Quadrupler Rectifier based Boost Converter for High Step up Application

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***Abstract*—The topology named as the semi quadrupler rec- tifier (SQAR) is obtained by replacing the fully active (four switches) bridge on the load side of a DualActive Bridge Rectifier (DAB) by a semi active (two switches and two diodes) bridge. In addition to the reduced number of active switches, the topology offers several other advantages including extended zero- voltage switching (ZVS), and smaller output filter requirement. An Isolated interleaved boost converter is developed based on proposed SQAR. Voltage quadrupler rectifier is derived in this paper to serve as the secondary rectification topology, which helps to extend the converter voltage gain. The output voltage is four times of the conventional full-bridge voltage rectifier with the same transformer ratio, which benefits to reduce the turns ratio of the transformer. Also, low voltage-rated diodes with high switching performance can be applied to improve the efficiency. The operation principle is analyzed and verified by Matlab Simulation.**

***Index Terms*— DC-DC converter, High Step up application, interleaved isolated boost converter, semi active quadrupler rectifier.**

I. INTRODUCTION

In the present scenario the demand for energy is increasing rapidly due to the increase in the human population as well as the industrial establishment all over the world. Inthisconditionthe renewable energy play an important role to replace the traditional resources such as fuel and coal. The distributed energy sources are mainly fuel cell, solar energy, wind energyetc. The PV energy should be the common interest in recent type due to which it is free ,green and inexhaustible comparing the others[1]-[4].There are mainly two different type of configurations are there, one is front end DC-DC converter and the other is a grid connected inverter. High frequency transformers are connected to a front end DC-DC converter and it will provide a high boost ratio and provide a galvanic isolation and makes a better safety purpose [5].The DC-DC converter has a high step up conversion ratio. And it reduces the size of the isolation transformer and the same time the overall efficiency of the converter is increased [6].The interleaved structure show some exciting characters such as continuous input current and it reducesthe input and output ripples. It have a great inherent current sharing capabilities and by taking low voltage rating devices it will reduces the switching stress and conduction losses[7]-[8].

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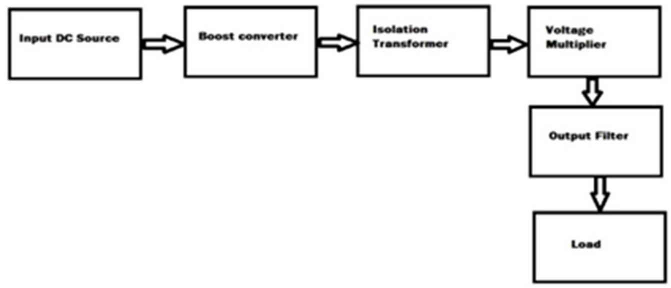

Fig. 1. Existing system

The Existing system consist of a DC source as it input and this input is given to a boost converter .As it the function of the boost , the input is get boosted up into co-responding boosting ratio. And this boost converter is an isolated one so it contain an isolated transformer .The main function of this transformer is to step up the output from the boost. The output from the transformer is again given into a voltage multiplier circuit that is a voltage doubler,Tripler or a quadrupler. The outputfromthismultipliersaregivenintoacapacitorfiltercircuit to filter out the ripples from the circuit and then it is given into a load even the diode are used in the rectification it shouldmakesomevoltagestressonthesecondaryside.[9]-[10]

Voltage fed converters are not good candidates for high power and high step up application ,current fed is good for this application. Current ripple is small due to input inductance and low voltage stress on rectifying devices. The high frequency transformer are efficient, compact and economical [11].The voltage stress generated on the secondary side switches is quite high and it could be normally equal to the output voltages. In order to reduce this and to increase the voltage gain voltage multipliers are normally used [12].

The Symmetrical voltage quadrupler makes the output four times more than the conventional full bridge voltage rectifier which help to reduce the turns of secondary winding.[13].Reduced the size and weight of the passive components such as input filter inductors ,auxiliary capacitor and output capacitor[14].No clamping or snubber circuit is required due to ZVS and series connected voltage doublers are used[15].Current fed topologies with a capacitive output filter inherently minimize diode rectifier ringing .Passive components used in the secondary side when the current passing through the transformer and the rectification circuit, it become discontinues and triangular form[16].

Large peak and rms value increases the current stress and conduction losses and it affect the efficiency of the converter. and during the power exchanging mode the primary side voltage is larger than secondary side by 1/n.[17] For the high step up application normal transformer ratio or duty cycle increases and it makes leakage inductance and primary side voltage stress increases [18].ZVS soft switching operation can be implemented for all the power switches in order to minimize the switching losses. The duty cycle of the main switches in the low voltage side is applied to balance the voltage on both sides . The overshoots on the rectifier are effectively suppressed sine the rectifier is clamped to output voltage[19].

Semi dual active bridge rectifier (SDAB) , small peak current passing through the transformer can be get utilized by the active switches and it makes the secondary side voltage controllable and higher voltage gain can be achieved ,by this it will reduces the duty ratio and turns ratio. It also reduce the voltage stress of the primary switches. Thereverserecoveryproblem on the secondary side can be partially solved by the leakage inductance .The converters from by replacing two active switches by two diodes[20].

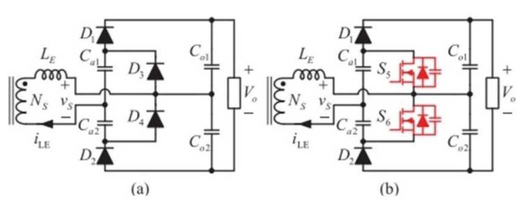

Fig. 2. (a) Passive voltage multiplier (b) SQAR Circuit

The passive voltage multiplier is a type of secondary rectification circuit which contains four diodes in its secondary side .This circuit resemblances to a voltage Quadrupler circuit and even though it makes a high voltage stress on the primary side switches and this may affect the efficiency and voltage gain of the circuit.
The proposed Semi Active Voltage Quadrupler[SAQR] is proposed to overcome all the limitation of the converters discussed above .In this SAQRs it is derived by replacing two active switches in the secondary side by two diodes or by adding an extra bidirectional switch. The main advantage of this paper is that to serve as the secondary rectification topology, which helps to extend the converter voltage gain and reduce the output diode voltage stresses. The output voltage is four times of the conventional full-bridge voltage rectifier with the same transformer ratio, which benefits to reduce the turns ratio of the transformer and decrease the parasitic parameters. Also, low voltage-rated diodes with high switching performance can be applied to improve the efficiency.

II. ANALYSIS OF THECONVERTER

The topology of the proposed interleaved isolated boost converter with SAQR is drawn in Fig. 3. The primary side of the converter is an interleaved isolated boost circuit, and the secondary side is a semi active rectifier composed of two active switches and two diodes. As illustrated in Fig.3, $L1$ and $L2$ are input inductors. The inductor LE can be implemented either only with the leakage inductance of the transformer or with an external inductor to achieve the desired value. Compared with the equivalent input stage given in [19] with the use of two coupled inductors, the small current stresses of the input inductors and transformer are offered with the interleaved isolated boost circuit, and it will be easy to optimal design of these magnetic components separately. The good consistency of drive circuits has been realized, and even without the dc blocking capacitor, the dc component of the transformer is very small and the core saturation problem isprevented fs is the switching frequency. The input inductors L1 and L2 are designed to ensure the current iL1 and iL2 are continuous in one switching cycle and $L_1 = L_2$. For simplification, the parasitic capacitances of MOSFET are ignored and the transformer is assumed to be ideal. There are 14 switching states in one switching period. Due to the symmetry of the circuit, only seven states are analyzed here a.

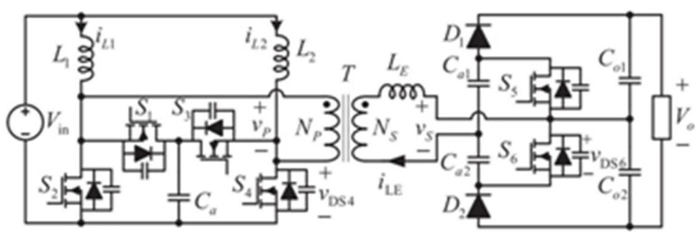

Fig. 3. Proposed Converter

The primary-side switches $S2$ and $S4$ are operated under the same duty cycle D and the driving signals for $S2$ and $S4$ have the 180 phase-shifted angle between each other. The switches $S1$ and $S2$ (or $S3$ and $S4$) are operated complementarity with reasonable dead-time. The secondary side switches $S5$ and $S6$ have a constant duty cycle of 0.5 and are under complementaryoperation.
Therefore, the voltage V_C on the capacitor C_a and the output voltage V_o will have the following relationship:
$V_C = V_o/4n$

State 1[t_0,t_1]
Before the condition t0 ,the switches S_2,S_4,S_6 are in ON condition and diode D1 is conducting the leakage inductor i_{Le} is less than 0, the energy stored in inductor i_{Le} is due to the previous condition the inductor L_1 and L_2 get charged due to input voltage .Capacitor C_{a2} and C_{o1} is in charged condition and the capacitor $C_{a2}$and C_{o2} is discharged .At the t_0 the switch S_2 is OFF and the body diode S_1 is began to conduct due to the energy stored in the L_1 andL_e
During the first mode mode of operation the inductor L_1 is previously charged due to V_{in}. The L_1 is discharged the diode D of the switch S_2 is forward biased condition and capacitor C_a is charged the inductor voltage V_L is come across the winding V_p and S_4 is ON condition due to ZVS.
The charge stored in the inductor L_e is gets discharged through the switch S6 and charges Capacitor C_{a2}.The capacitor C_{a1} discharges to load and make the diode D1 Of the secondary side is conducting and

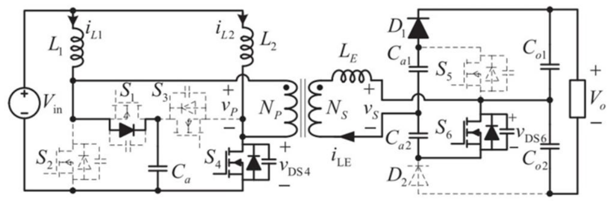

Fig. 4. State1

freely conducts the load to maintain a dead time . Capacitor $C02$ is discharges and make the $Co1$ is charges to the load

Thevalueofinductorcurrentatthestate1Inthisstate,the inductor current i_{LE} ,i_{L1}, and i_{L2} can be calculated by i_{LE}(t)=(nVC + V_o/ 4 (t t_0)/L_E + i_{LE}(t_0)

i_L1(t)=(V_{in} V_C) (t t0)/L1 + iL1 (t_0)

i_{L2}(t) = V_in (t t_0)/L_2 + i_{L2} (t_0).

State 2[t_1,t_2]

During this mode of operation the switch S_1 is in turned ON condition with ZVS condition across the switch. The inductor current iLe recovers to zero and the end of this mode the diode D_1 is turnsoff.theD_1 is remain on forward bias through the discharged capacitor C_{a1} . when the capacitor C_{a1} when the capacitor c_{a1} discharges completely through the diode D_1 .The diode D_1 gets turn off naturally without any reverse recoveryloss.

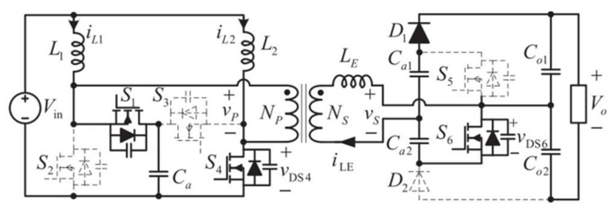

Fig. 5. State2

State3 [t_2,t_3]

In this mode of operation the switches $S2$ and $S4$ are in ON condition the inductor current iLe recovers to zero .The Le gets charged by the voltage across $Vca$and the capacitor voltage $ca2$.

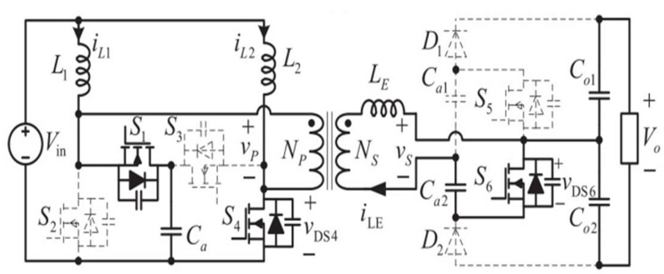

Fig. 6. State3

In the previous condition capacitor c_{a2} is in charged mode and the capacitor is discharges to charges the inductor .The capacitor c_{o2} is gets discharges to the load through C_{a1} to theload

State4[t_3,t_4]

At the t_3 the switch s_6 is gets turns off .the body diode of S_5 began to conduct .the diode D_2 conducts due the energy stored in L_e .The capacitor C_{a1} and C_{o2} are in charged condition and capacitor C_{o1} and C_{a2} is in discharged condition.

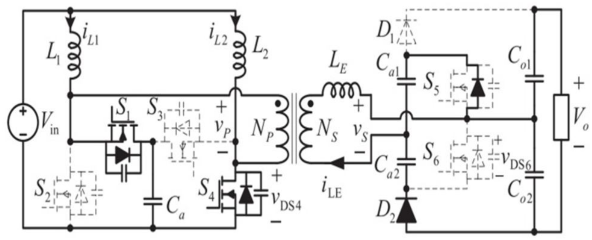

Fig. 7. State4

The inductor current LE remains in the same condition .the diode is in forward biased condition .the inductor LE is also charges the capacitor $Ca1$ that is the body diode of the $S5$ conduct and this makes $Ca1$ to conduct.

State5[$t4$,$t5$]

The switch $S5$ gets turn ON due to the ZCS condition.in this mode the energy is continuously transferred from source to load and this transferring on energy from source to load gets stop when the switch $S1$ gets turns off at the interval $t5$.

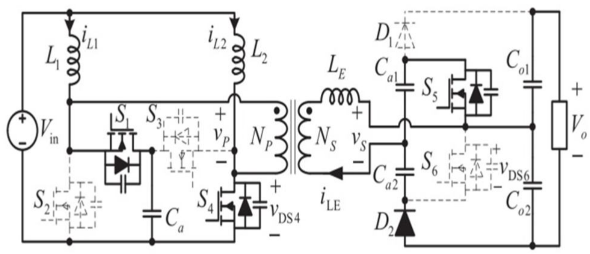

Fig. 8. State5

In the secondary side the inductor L_E gets charged by the capacitor voltage $V_{ca}$and the capacitor C_{a2} The switch S_5 is gets turn On condition the diode D_2 is forward biased , the capacitor C_{o2} and C_{a1} is in charged condition.

State6 [t_5,t_6]

The switchS_1 gets turn OFF during the time interval of t_5 as when S_1 turn OFF the body diode of S_2 starts conducting due to energy stored in L_1 and L_E .

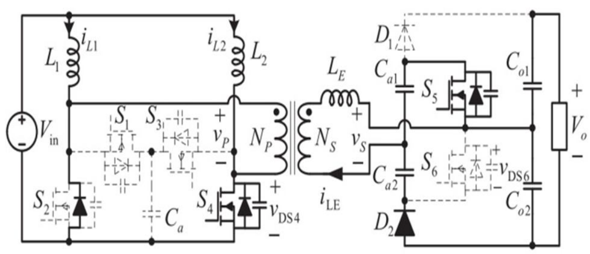

Fig. 9. State6

Energy stored in LE is only moved to the load And the $L1$ is get charged by the input voltage Vin.and inductor $L1$ and the diode . The current flow through the $L1$ should be thealgebraicsumoftheinputaswellasthediodecurrent.

Stat7[$t6$,$t7$]

At the $t6$ condition $S2$ turns On with ZVS condition .the Inductor $L1$ and $L2$ is charged by the input voltage .the inductor LE is charged by the discharged voltage of $Vca$and the voltage of $Ca2$.

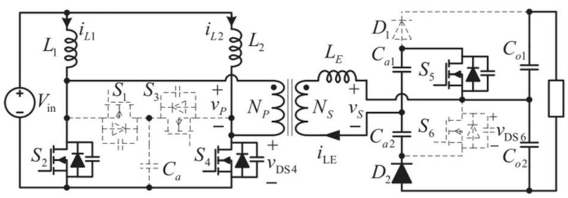

Fig. 10. State7

The Switch $S4$ is comes into turn off condition of t7 and this is the end of the state .
The inductor current iLE and $iL1$ can be calculated by
$iLE(t) = Vo\ (t\ \ t5)\ /4LE\ + iLE\ (t5)$
$iL1(t) = Vin\ (t\ \ t5)\ /L1\ + iL1\ (t5)$.

III. SIMULATIONRESULTS

The designed converter rated at 500 W was first simulated using thethe MATLAB version 2015 to verify analysis
, design and performance of the converter .These Matlab simulations are are plotted under the following conditions: Vin = 24 V,Vo = 380 V,VC = 47.5 V,fs = 100 kHz, n = 2, and LE = 8.5 H.
A PWM control is used to generate the pulses for the switches. By using this PWM control method it is comparing the Available load voltage with a desired load voltage and the difference between these two voltage is compared and an error signal is get generated and this error signal is given to a PI controller and then to a saturation unit to produce a corresponding duty cycle for the switches in the primary side and the switches at the secondary side have a constant duty cycle.

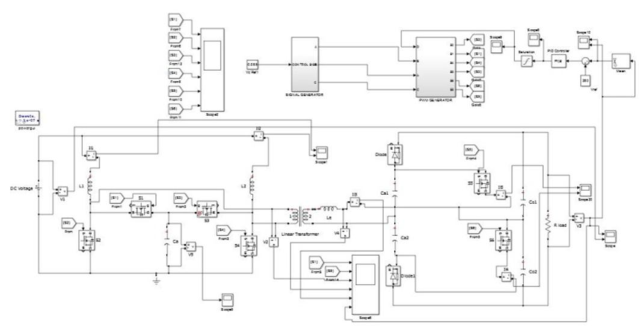

Fig. 11. Simulation diagram

Due to the energy store dininductorLE,theinductorcurrent iLE would flow through the body diode of MOSFET during dead time before turning on the MOSFET, and ZVS is achieved. The ZVS conditions of primary-side switches are determined by various factors such as the inductor LE , the input inductor L, and the input/output power. The inductor $L1$ and $L2$ have good current-sharing performance. Once the body diode of MOSFET is onbeforeturningonthe MOSFET, ZVScan be achieved.

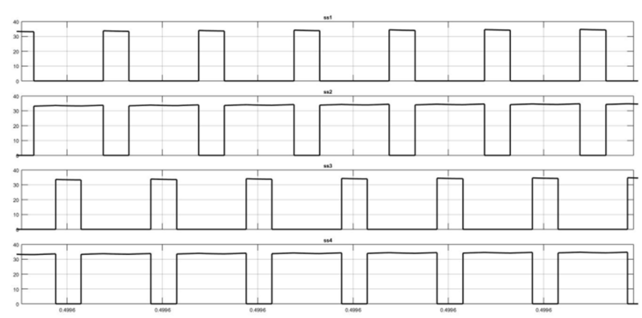

Fig. 12. Voltage stress across the switches s_1 , s_2 , s_3 , s_4 of SAQR

On comparing the two wave forms of a passive voltage multiplier and a SQAR circuit . The voltage Stress between the switches in the case of a passive voltage multiplier is quitehigh.anditgivesavoltagestressattherangeof60V
.On coming to SQAR converter the stress rate between the primary side switches is quite low .it is in the range of 30V. hence it can be said that by replacing the passive voltage multiplier by a SQAR the voltage stress across the switch can be minimized.

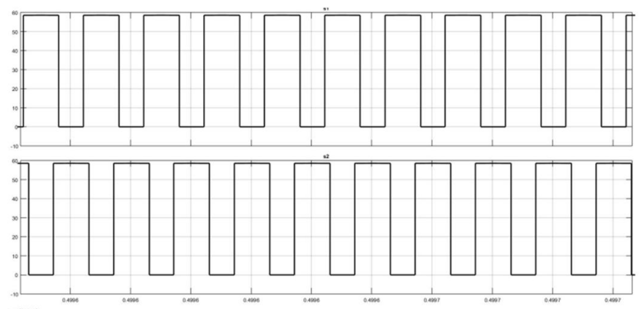

Fig. 13. Voltage stress across the switches S_1,S_2 of Passive Voltage Multiplier

From the simulation analysis, it can be obtain that the main dc component of input inductor current is opposite to the direction of the current that can flow through the body diode of S2 and S4.This is the reason why the ZVS range of S2 and S4 is narrow.
IftheoutputcapacitancesofS2andS4are taken into considerations, the small current ni_{LE}, i_L will be hard to fully discharge the output capacitance during the dead time, which makes the ZVS turn on hard to realize.

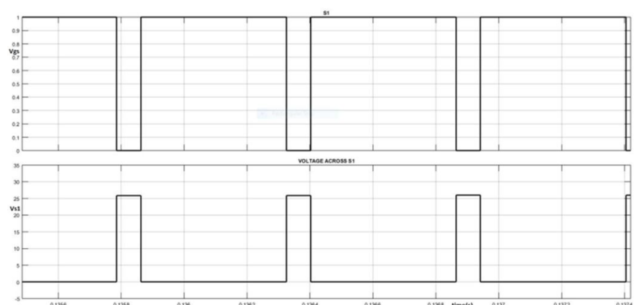

Fig. 14. Zero voltage situation across switch S_1

From the simulation graph a ZVS condition is get obtained acrosstheswitchS1andsimilarlyaZEROvoltagecondition are get obtained across the other switch esin the primary side as well as secondary side. But To make the ZVS turn on of S2 and S4, the large current ripple of $I_L$is required. However, higher current stress and larger conduction losses are induced due to the increased peak and rms current values, which will do harm to the efficiency of the converter. the turns ratio of the transformer is designed to ensure the converter operated with D. The inductor L_E determines the power transmission capability of the proposed converter and it has a great effect on the rms values of i_{LE} , which will affect the conduction losses of the converter.
The ZVS soft switching performance of primary-side upper switches (S1 and S3) and secondary-side switches (S5 and S6) can be achieved. However, the ZVS performance is lost for primary-side lower switches (S2 and S4), which is because only a small current is used to discharge the output capacitance's of S2 and S4. the ZVS soft switching performance of primary-side upper switches (S1 and S3) and secondary-side switches (S5 and S6) can be achieved. However, the ZVS performance is lost for primary-side lower switches (S2 and S4), which is because only a small current is used to discharge the output capacitances of S2 and S4.

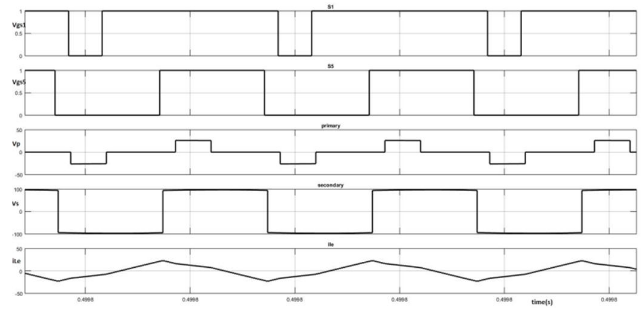

Fig. 15. Pulse given for Switch S1, S5 and there coresponding primary ,secondary and leakage inductor current

For the interleaved isolated boost converter with passive VM the voltage VP will be always larger than VS /n, VC is greater than Vo/ 4n. The voltage gain of the converter with passive VM can be given by G = Vo/Vin is less than 4nVC /Vin
= 4n/ (1 D). the voltage gain of the converter with passive VM is always smaller than the SAQR-based converter. To obtain the same voltage gain with the same turns ratio n, the duty cycle of the SAQR converter is smaller, and smaller voltage stresses on primary-side switches have been gained.
The rms and peak values of the inductor current iLE of the leakage inductor in the SAQR converter are smaller than that of the converter with passive VM, mainly in its peak values. Thus, SAQR provides a better performances with smaller conduction losses and lower current stresses compared with the converter with passive rectifiers. And it has less winding turns and smaller air gap ,It prevent unreliable saturation of the inductors in the SAQR converter. The SAQR-based converter maintain a better performances with smaller voltage stresses on the primary-sides witches, lower peak/rmscurrents of LE , lower current stress , and higher voltage conversion gain.

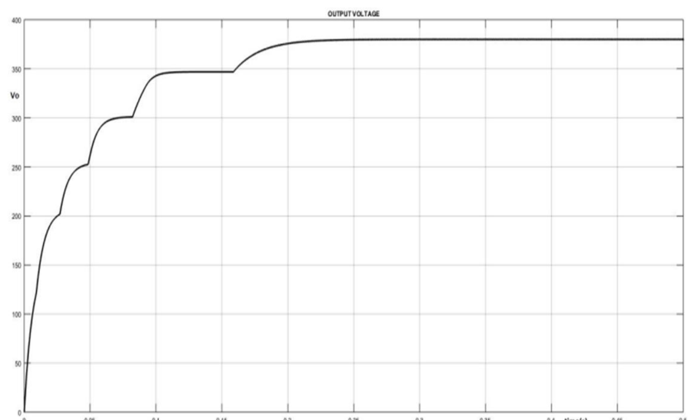

Fig. 16. Output Across the Load

The comparisons between the SAQR converter and the converter with passive VM efficiencies of the SAQR converter are higher within full voltage range with different output loads. SAQRs and the derived converter are good candidates for high step-up dc-dc conversion applications.

IV. CONCLUSION

This semi quadrupler rectifier (SQAR) is to full fill zero- voltage switching (ZVS), and smaller output filterrequirement. An Isolated interleaved boost converter is developed based on proposed SQAR. Voltage quadrupler rectifier is to serve as the secondary rectification topology;It extends the converter voltage gain and reduce the output diode voltage stresses. The output voltage is four times of the conventional full-bridge voltagerectifierwiththesametransformerratio,whichbenefits to reduce the turns ratio of the transformer. Also, low voltage- rated diodes with high switching performance can be applied to improve the efficiency. The operation principle is analyzed and verified by a 24V/380V Matlab simulation .

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