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Implementation of Closed Loop Control of High Step up Interleaved Converter with VoltageMultiplier Module and Renewable Energy System

M.AVINASH
M-tech Student Scholar
Department of Electrical & Electronics Engineering,
Sri Venkateswara College of Engineering and
Technology, Etcherla; Srikakulam (Dt); A.P, India.

M.SATISH KUMAR
Assistant Professor
Department of Electrical & Electronics Engineering,
Sri Venkateswara College of Engineering and
Technology, Etcherla; Srikakulam (Dt); A.P, India.

Abstract-- A High step-up converter suitable for renewableenergy system is designed in this paper. Using a conventionalinterleaved boost converter, accompanied by a voltage multipliermodule composed of switched capacitors and coupled inductors,high step-up gain is obtained without operating at extreme dutyratio. The topology of the proposed converter reduces thecurrent stress. The topology constrains the input current ripple,and hence the conduction loss reduces. The circuit also increasesthe lifetime of the source. Because of the lossless passive clampperformance, the leakage energy can be recycled to the outputterminal. The low-voltage-rated MOSFETs can be adopted for reductions of conduction losses and cost. In addition, due to the lossless passive clamp performance, leakage energy is recycled to the output terminal.Hence, large voltage spikes across the main switches are alleviated, and the efficiency is improved. Closed loop control automatically maintains a precise output voltage regardless of variation in input voltage and load conditions.

Index Terms—RES, DC-DC Converter, high step-up converter, voltage multiplier module.

I.INTRODUCTION

Renewable energy being the best solution andemployed all over the world to satisfy the energy shortageexisting without environmental contamination[1]-[3].Among the renewable energies available the mostpromising energy is Photovoltaic (PV) energy. Though PVsystem installation cost is high, it has lots of pros, as the systemis long lasting and maintenance frees [4]. Now-a-days, PVsystem has grasped the attention of the researchers, but highinstallation cost and low conversion efficiency are the majordrawbacks.

To extract maximum power from the PV system MPPTtechnique can be implemented to the boost converters. Byadjusting the duty ratio of the converter, maximum powerdelivered can be tracked by the PV panel. As the energygenerated by the PV system is not sufficient (i.e.) very lowvoltage. IN order to overcome, the aforementioned cons in thePV system. The DC/DC boost converter is employed in betweenthe power generation stage and the load shown in the Fig.1. Thevoltage is boosted and high voltage is achieved.But, our conventional power converter has low efficiencydue to the poor conversion ratio. The semiconductor devices areused as the switch in the converter. Since, this switch sufferswith voltage stress, the switching losses increases and efficiencyis decreased [5].

The proposed converter is the integration of voltagemultiplier module with the conventional interleaved boostconverter. Coupled inductors and switched capacitors togetherconstitute the voltage multiplier module [6]. The design of thecoupled inductors can be used to extend step-up gain andhigher voltage conversion ratio is offered by the switchedcapacitors. Moreover, the energy stored in the magnetizinginductor will transfer via three respective paths when one ofthe switches turns off and thus current distribution decreases.Hence, the conduction losses decrease because of loweffective current. The currents through some diodes decreaseto zero before they turn off and hence diode reverse recoverylosses are also reduce. The objective of this paper is todevelop a converter with low switching losses, reducedvoltage and current stress and reduced conduction loss. Theleakage inductance of the isolation transformer, resulting inhigh voltage spike during switching transition is a major issue [7].The freewheeling current due to the leakage inductance willincrease the conduction losses and reduce the duty cycle. Anotable approach is to pre charge the leakage inductance andto raise its current level up to that of the current-fed inductor,thus reducing their current difference and voltage spikes. Asthe current level varies with variation in the load, it is difficultto tune the switching timing diagram to match these twocurrents [8].

Renewable energy systems generate low voltage output; thus, high step-up dc/dc converters are widely employed in many renewable energy applications. The DC-DC converter with high step-up voltage gain is widely used for many applications. Thehigh step-up conversion may require two-stage converters with cascade structure for enough step-up gain, which decreases the efficiency and increases the cost. The conventional interleaved boost converter is an excellent candidate for high-power applications and power factor correction. Unfortunately, the step-up gain is limited, and the voltage stresses on semiconductor components are equal to output voltage [9]. Thus, a high step-up converter is seen as an important stage in the system because such a system requires a sufficientlyhigh step-up conversion with high efficiency. Conventional step-up converters, such as the boost converter and flyback converter, cannot achieve a high step-up conversion with high efficiency because of the resistances of elements or leakage inductance;also the voltage stresses are large [10].

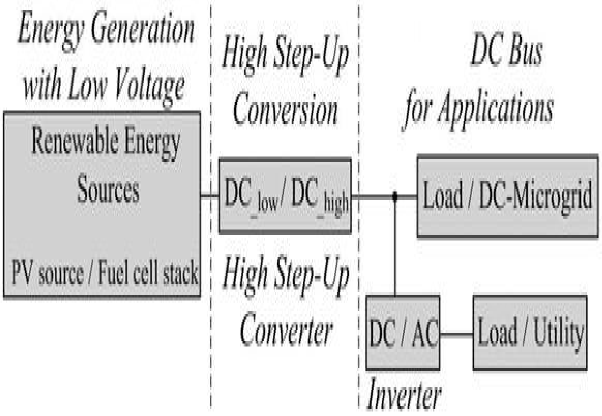

Fig.1.Block diagram of renewable energy system

The proposed converter is a conventional interleaved boost converter integrated with a voltage multiplier module, and the voltage multiplier module is composed of switched capacitors and coupled inductors. The coupled inductors can be designed to extend step-up gain, and the switched capacitors offer extra voltage conversion ratio. In addition, when one of the switches turns off, the energy stored in the magnetizing inductor will transfer via three respective paths; thus, the current distribution not only decreases the conduction losses by lower effective current but also makes currents through some diodes decrease to zero before they turn off, which alleviate diode reverse recovery losses.

II. CLOSED LOOP GRID CONNECTED SYSTEMS

DC motors are used extensively in adjustable speeddrives and position control applications. Their speeds lowerthe base speeds can be controlled by armature – voltagecontrol. Speeds over the base speed are obtained by field-fluxcontrol method. As speed control method for DC motors aresimpler and less expensive than those for AC motors, DCmotors are preferred where wide speed range control isrequired. For this control objective of DC drive is obtained byusing power electronic device fed renewable energygeneration scheme now implemented in many industrialapplications. Fig. 2 shows the schematic diagram that the PVpanel is connected to the DC motor through proposedconverter by a closed loop control. In recent years, there hasbeen an upsurge of interest in solar photovoltaic (PV) energysystems in both industry and academia [7]. In typical PVpower generation systems, several PV panels are connected inseries and parallel to form an array and feed energy to a singlecentralized converter [8]. An alternative approach is to use aDC module, which is a combination of one PV panel and onepower conditioning unit, to feed power directly into the DC load [9].

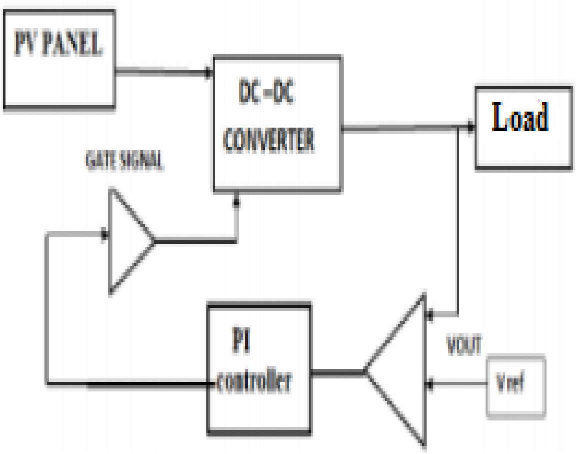

Fig.2.General Schematic of standalone system with closed loop control and grid connected systems.

A DC–DC converter with a high step-up voltage gain isused for several applications, such as high-intensity dischargelamp ballasts for automobile headlamps, fuel cell energyconversion systems, solar-cell energy conversion systems andbattery backup systems for uninterruptible power supplies.Theoretically, a dc–dc boost converter can achieve a highstep-up voltage gain with an extremely high duty ratio.However, in practice, the step-up voltage gain is limited dueto the effect of power switches, rectifier diodes and theequivalent series resistance (ESR) [10] of inductors andcapacitors.

III. OPERATING PRINCIPLES

The proposed high step-up interleaved converter with a voltagemultiplier module is shown in Fig.3. The voltage multipliermodule is composed of two coupled inductors and two switchedcapacitors and is inserted between a conventional interleaved boost converter to form a modified boost–flyback–forward interleavedstructure. When the switches turn off by turn, thephase whose switch is in OFF state performs as a flybackconverter, and the other phase whose switch is in ON stateperforms as a forward converter.Primary windings of the coupled inductors with *Np* turnsare employed to decrease input current ripple, and secondarywindings of the coupled inductors with *Ns* turns are connectedin series to extend voltage gain. The turn ratios of the coupledinductors are the same. The coupling references of the inductorsare denoted by "·" and "*".

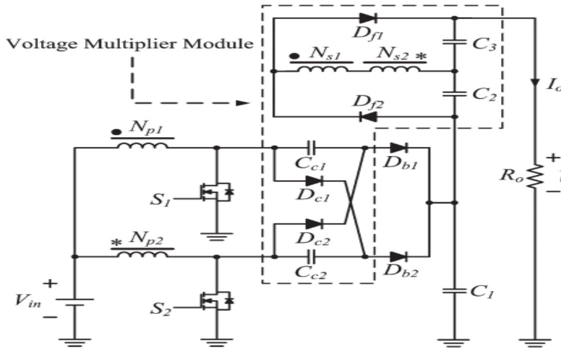

Fig.3. Proposed high step-up converter.

The DC-DC converter requires large step-up voltage conversion from low voltage obtained from the panel to the required voltage level for the application. The previous research on various converters for high step-up applications has included analyses of the switched – capacitor type, the voltage-lift type, the capacitor-diode voltage multiplier type and the boost type integrated with coupled inductor, these converters by increasing turns ratio of coupled inductor obtain higher voltage gain than conventional boost converter. Some converters successfully combined boost and fly back converters, since various converter combinations are developed to carryout high step up voltage gain by using the coupled-inductor technique. The efficiency and voltage gain of the DC-DC boost converter are constrained by either switches or the reverse recovery issues of the diodes.

At $t = t_0$, the power switch S_2 remains inON state, and the other power switch S_1 begins to turn on. Thediodes D_{c1}, D_{c2}, D_{b1}, D_{b2}, and D_{f1} are reversed biased. The series leakage inductors L_s quicklyrelease the stored energy to the output terminal via flyback–forward diode D_{f2}, and the current through series leakageinductors L_s decreases to zero. Thus, the magnetizing inductorL_{m1} still transfers energy to the secondary side of coupledinductors. The current through leakage inductor L_{k1} increaseslinearly and the other current through leakage inductor L_{k2}decreases linearly.At $t = t_1$, both of the power switches $S_1$and S_2 remain in ON state, and all diodes are reversed biased. Both currents through leakage inductorsL_{k1} and L_{k2} are increased linearly due to charging by inputvoltage source V_{in}.At $t = t_2$, the power switch S_1 remainsin ONstate, and the other power switch S_2 begins to turn off.The diodes D_{c1}, D_{b1}, and D_{f2} are reversed biased. The energy stored in magnetizing inductor L_{m2}transfers to the secondary side of coupled inductors, and the other modes of operations are presented in the simulation cases.

IV. STEADY-STATE ANALYSIS

The transient characteristics of circuitry are disregardedto simplify the circuit performance analysis of the proposedconverter in CCM, and some formulated assumptions are asfollows.1) All of the components in the proposed converter are ideal.2) Leakage inductors $Lk1$, $Lk2$, and Ls are neglected.3) Voltages on all capacitors are considered to be constantbecause of infinitely large capacitance.4) Due to the completely symmetrical interleaved structure,the related components are defined as the correspondingsymbols such as $Dc1$ and $Dc2$ defined as Dc.

A.Step-Up Gain

The voltage on clamp capacitor Cc can be regarded as anoutput voltage of the boost converter; thus, voltage VCccan bederived from

$$V_{CC} = \frac{1}{1-D}V_{in} \qquad (1)$$

When one of the switches turns off, voltage $VC1$ can obtain adouble output voltage of the boost converter derived from

$$V_{C1} = \frac{1}{1-D}V_{in} + V_{CC} = \frac{2}{1-D}V_{in} \qquad (2)$$

The output filter capacitors $C2$ and $C3$ are charged by energytransformation from the primary side. When $S2$ is in ON stateand $S1$ is in OFF state, $VC2$ is equal to the induced voltage of$Ns1$ plus the induced voltage of $Ns2$, and when $S1$ is in ON stateand $S2$ is in OFF state, $VC3$ is also equal to the induced voltageof $Ns1$ plus the induced voltage of $Ns2$. Thus, voltages $VC2$ and$VC3$ can be derived from

$$V_{C2} = V_{C3} = n.V_{in}\left(1+\frac{D}{1+D}\right) = \frac{n}{1-D}V_{in} \quad (3)$$

The output voltage can be derived from

$$V_o = V_{C1} + V_{C2} + V_{C3} = \frac{2n+2}{1-D}V_{in} \qquad (4)$$

In addition, the voltage gain of the proposed converter is

$$\frac{V_o}{V_{in}} = \frac{2n+2}{1-D} \qquad (5)$$

Equation (5) confirms that the proposed converter has a highstep-up voltage gain without an extreme duty cycle. The curveof the voltage gain related to turn ratio n and duty cycle isshown in Fig.4. When the duty cycle is merely 0.6, the voltagegain reaches ten at a turn ratio n of one; the voltage gain reaches30 at a turn ratio n of five.

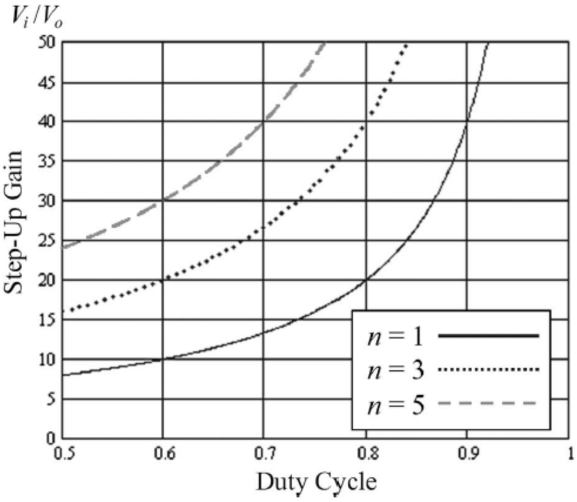

Fig. 4.Voltage gain versus turn ratio *n* and duty cycle.

B. Voltage Stress on Semiconductor Component

The voltage ripples on the capacitors are ignored to simplifythe voltage stress analysis of the components of the proposedconverter. The voltage stress on power switch *S* is clamped and derived from-

$$V_{S1} = V_{S2} = \frac{2}{1-D}V_{in} = \frac{1}{2n+2}V_O \qquad (6)$$

Equation (6) confirms that low-voltage-rated MOSFET withlow *R*DS(ON) can be adopted for the proposed converter toreduce conduction losses and costs. The voltage stress on thepower switch *S* accounts for a fourth of output voltage *Vo*, evenif turn ratio *n* is one. This feature makes the proposed convertersuitable for high step-up and high-power applications.

The voltage stress on diode *Dc* is equal to *VC*1, and thevoltage stress on diode *Db* is voltage *VC*1 minus voltage *VCc*.These voltage stresses can be derived from

$$V_{Dc1} = V_{Dc2} = \frac{2}{1-D}V_{in} = \frac{1}{n+1}V_o(7)$$

$$V_{Db1} = V_{Db2} = V_{C1} - V_{C2} = \frac{1}{1-D}V_{in} \qquad (8)$$

The voltage stress on diode *Db* is close to the voltage stresson power switch *S*. Although the voltage stress on diode *Dc* islarger, it accounts for only half of output voltage *Vo* at a turnratio *n* of one. The voltage stresses on the diodes are lower asthe voltage gain is extended by increasing turn ratio *n*.The voltage stress on diode *Df* equals the *VC*2 plus *VC*3,which can be derived from

$$V_{Df1} = V_{Df1=}\frac{2n}{1-D}V_{in} = \frac{n}{n+1}V_O\,(9)$$

Although the voltage stress on the diode Df increases as theturn ratio n increases, the voltage stress on the diodes Df isalways lower than the output voltage.

V.SIMULATION RESULTS

Here the simulation is carried out by two different cases they are 1) high step-up interleaved converter with voltage multiplier module 2) closed-loop control of interleaved converter with voltage multiplier module

Case-1High step-up interleaved converter with voltage multiplier module

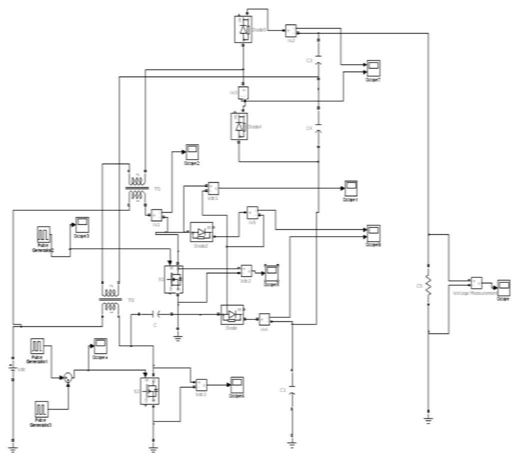

Fig.5.Simulink model of high step-up interleaved converter with voltage multiplier module

Fig.5 shows the simulink model of proposed converter operating in continuous conduction mode and the duty cycles of the power switches during steady operation are greater than 0.5 and are interleaved with a 180° phase shift. Fig.6& 7 shows the gating pulse to power switches S1 and S2. The other plot shows the voltage across the power switches S1 and S2. Fig.8 shows the voltage stresses on clamp diodes Dc1 and Dc2. These voltage stresses are doubles of voltage stresses on power switches S1 and S2. Fig.9 shows the output voltage of the high step-up interleaved converter with voltage multiplier module.

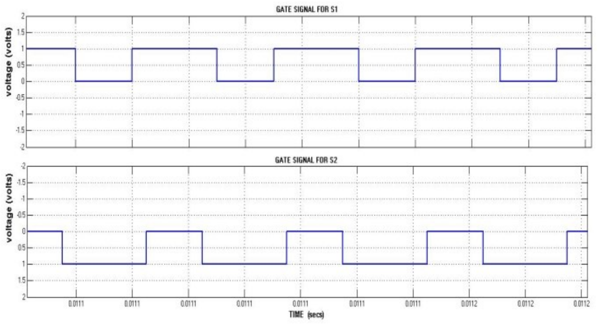

Fig.6.Power switch S1 gating pulse and output voltage

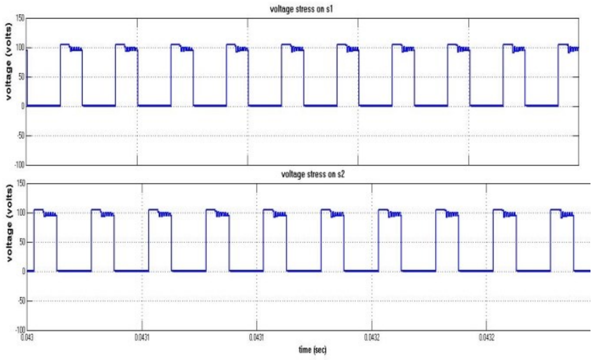

Fig.7.Power switch S2 gating pulse and output voltage

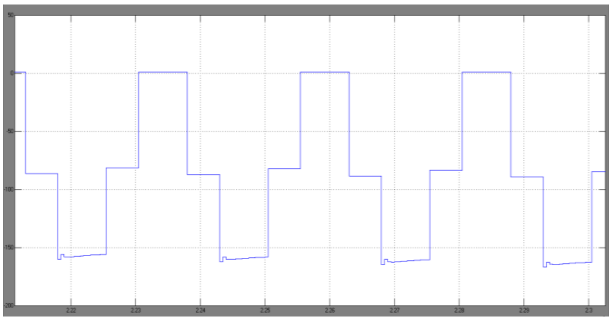

Fig.8.Voltage stresses onclamp diodes.

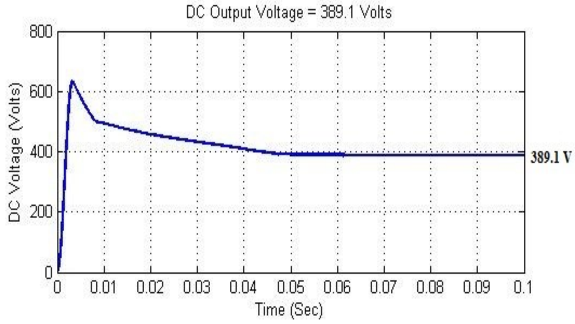

Fig.9. Output Voltage of High Step-Up Interleaved Converter With Voltage Multiplier Module.

Case-2 Closed-loop control of interleaved converter with voltage multiplier module

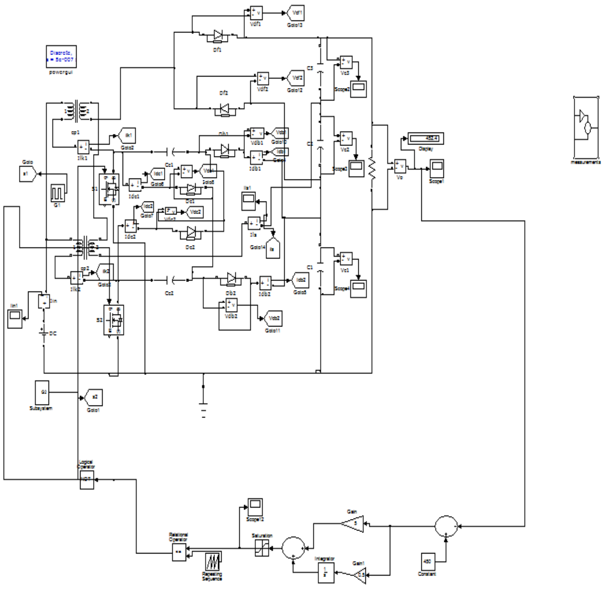

Fig.10 Simulink Model Of Closed Loop Control Of Interleaved Converter With Voltage Multiplier Module.

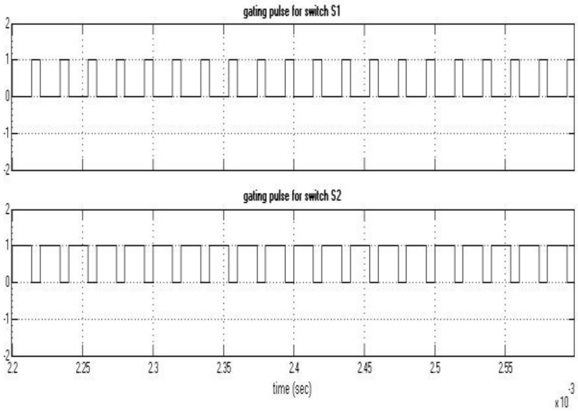

Fig.11. Gating pulse of power switches S1 and S2.

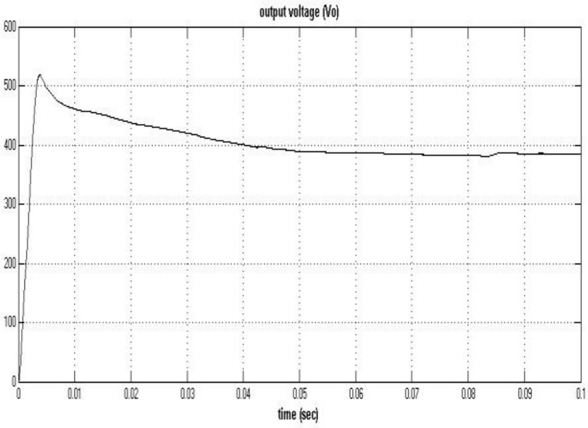

Fig.12. Output Voltage of Closed Loop Control Of Interleaved Converter With Voltage Multiplier Module.

Fig.10 shows the Simulink model of closed loop control of interleaved converter with voltage multiplier module. In closed loop the actual output voltage is compared with the given reference voltage to give the required output voltage. Fig.11. shows the gating pulse to power switches S1 and S2. Fig.12 shows the output voltage of closed loop control of interleaved converter with voltage multiplier module.

VI. CONCLUSION

This paper has presented the theoretical analysis of steady state, related consideration, simulation results, for the proposed converter. The proposed converter has successfully implemented an efficienthigh step-up conversion through the voltage multiplier module. The interleaved structure reduces the input current ripple and distributes the cur- rent through each component. The proposed converterhas successfully implemented an efficient high step-up conversionthrough the voltage multiplier module with high efficiency. Leakage energy is recycled and voltage spikes are constrained. Voltage stress on power switch is also lower than output voltage. The closed loop control automatically maintains a precise output voltage regardless of variation in input voltage and load conditions. These all simulation results are tested and verified by using MATLAB/SIMULINK software.

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METTA AVINASH was born in 1991month of may 23rd. He received his B.Tech degree in Electrical andelectronics engineering from Gayathri Vidhya parishad college of engineering in 2013. At present pursuing M.Tech specialization in Power electronics in Sri Venkateswara college of Engineering,Etcherla,Srikakulam district, Andhra Pradesh,India.

MACHERLA SATISH KUMAR Completed his graduation in Electrical and Electronics Engineering from JNTUK in the Year 2012 and received his M.Tech from JNTUK in 2014.He is presently working as Assistant Professor in Department of Electrical &Electronics Engineering in Sri Venkateswara College Of Engineering Etcherla, Srikakulam district, Andhra Pradesh ,India. His areas of Interest are Power Electronics &Electrical Drives