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Series-Connected Current-Source-Mode Dual Output ZVS Converter with High Step-Down Ratio

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ABSTRACT: Power converters are widely used in many applications.If the loads are required to be fed by low voltage, converters with high step down ratio are used. In this the two stage multiple output converter achieves a high voltage step down without the use of transformer. The use of current source mode (CSM) converter results low voltage stress in switches and simplified control. The first stage of this configuration is regulated to provide a constant current to second stage. Due to the zero voltage switching in the first stage of converter, switching losses are reduced. The second stage consists of series CSM boost converters. DC output voltage of the converter is much lower than the DC input voltage. The converter can be used for the applications such as Light Emitting Diodes and Battery Chargers. Maximum efficiency of the converter is 95.62% . The converter offers low voltage ripple. The performance study of the converter is carried out with MATLAB/SIMULINK R2017a.

KEYWORDS: High step down ratio, Current sourcemode(CSM)converter, Zero Voltage Switching.

I.INTRODUCTION

In applications where the loads are required to be fed by a low voltage, such as battery chargers, portable electronic devices, light emitting-diodes (LEDs) and so on power converters with a high step-down ratio are used. In such converter, the step down operation is achieved simply by turning on and off the switching devices for a desired duty cycle. In general, there are three common ways to realize a high step-down ratio,namely multiphase converters, multilevel converters and input series-connected converters. In the multiphase configuration, an interleaved buck converter is the basic structure [6], which steps down the input voltage and at the same time reduces the current and amplitude of ripple current in each output. However, additional coupled inductors cause poor dynamic response, high cost, relatively large physical size and low scalability. Another type of converters used for high-input voltage applications is the multilevel converter [9]. The basic structure consists of a series connection of submodules. With the addition of submodules and modifications, more switches are introduced, thus leads to lower reliability and higher complexity of the configurations and the corresponding control methods. Input-series connected converter circuits [3] are used to achieve a high voltage stepdown ratio. The basic idea is to step down the voltage through series connection of submodules. When used in high voltage applications, each of the series-connected converters shares part of the high input voltage. If a higher step-down ratio is desired, more modules can be added to share the input voltage illustrates a charge control with an input voltage feed forward for an input-series-output-parallel-connected converter configuration for high speed train power system application. The control scheme accomplishes the output current sharing for the output-parallel-connected modules as well as input voltage sharing for input series connected modules for all operating condition including transients. It also offers the robustness for the input voltage sharing control according to components mismatches among the modules. This configuration provides a high voltage system allowing a higher switching frequency for a lighter system weight and smaller size. Conventional DC-DC converters are called voltage-source mode (VSM) converters. When VSM converters are connected in series, voltage balancing requires special control attention. The two stage multiple-output converter configuration achieves a high voltage step-down ratio without use of transformer based on series-connected current-source-mode boost converter [2],[10]. Though the high frequency operation reduces size of the converter, it results increased power losses in hard switching converters. This results reduction in the efficiency of converter and leads to increase in the switching stress. High frequency also cause Electromagnetic Interference (EMI). In this paper a two stage multiple-output converter configuration achieving a high

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voltage step-down ratio with zero voltage switching circuit is proposed. The problems of hard switching converter can be solved by soft switched zero voltage switching configuration. A two stage structure consist of high voltage section and low voltage section. High voltage stage is designed to provide a regulated current to a number of series-connected current-source-mode (CSM) converters. CSM converters are theoretically dual of boost converter. For an input voltage, the first stage needs to convert the input voltage to a regulated output current. The CSM boost converters provide the required current to the corresponding loads. This configuration realizes voltage step-down three times through two stages. In this case, the voltage stress of switches in the low-voltage section will remain low and with the use of ZVS circuit voltage stress of switch in the high voltage section also remain low.

II.OPERATING PRINCIPLES

The circuit diagram of CSM dual output ZVS converter is shown in Figure 1. The proposed converter is with a two stage structure. First stage is a high voltage section which is a buck converter which consist of a switch S_0, diode $D_0$and an inductor L_0. The switching-on and switching-off instants of switch S_0 occurs at zero voltage, which helps to reduce switching losses, switching stress and EMI. Diode $D_r$is connected across the switch to ensure turn on instant of power switch at zero voltage. The inductor $L_0$is connected in series and capacitor C_r is connected in parallel with the switch to limit di/dt and dv/dt of the switch respectively. Second stage is a low voltage section consist of two series connected current source mode (CSM) converters. Each CSM boost converter consist of capacitors C_1, C_2 switches S_1, S_2 and diodes D_1, D_2 and smoothing inductors L_1, L_2.

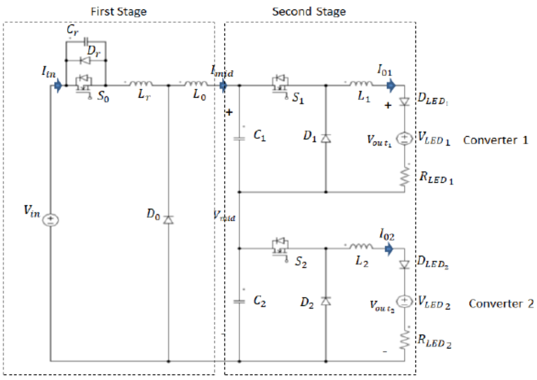

Fig. 1. Series-Connected Current-source-Mode Dual Output ZVS Converter

I_{mid} is the input current of the second stage, which is also the output current of the first stage. I_{01} and I_{02} represent the output currents of CSM boost converters; and D_1, $D_2$are the corresponding steady-state duty cycles. The steady state power balance gives

$$V_{mid}I_{mid} = V_{01}I_{01} + V_{02}I_{02}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where V_{01}; V_{02} are the output voltages of CSM boost converters. Soft switching is applied to the switch in ZVS converter. Feature ZVS converter is applicable to high frequency application.

Parameters are

Characteristic impedance $Z_0 = L_r/C_r$

Resonant angular frequency $\omega_0 = 1/(Lr * Cr)_{1/2}$

Resonant frequency $fr = \omega_0/2\pi$

Switching period = Ts

The key operating waveforms of the CSM Dual Output ZVS converter are indicated in Fig. 2. The proposed configuration has three switches. Each switch can operate in two modesnamely ON and OFF. Since the switching time of S_0; $S_1$and S_2 are independent of each other, no timing control is required. There are three possible modes of operation.

Mode 1: S_0; S_1 and S_2 are ON

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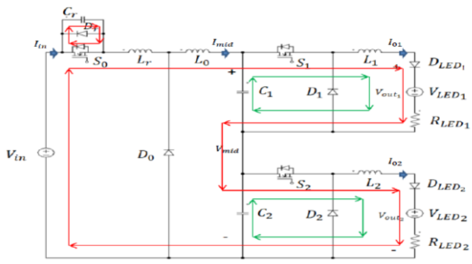

Fig. 2. Equivalent circuit of Mode 1

Input voltage source charges L_r, $L_0$and supplies current to the loads of two CSM boost converters while C_1, C_2 discharges to the loads. Cr suddenly discharges to zero voltage.

Mode 2: S_0 is OFF S_1 and S_2 are ON

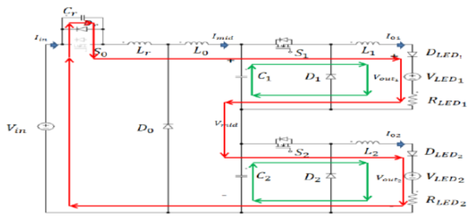

Fig. 3. Equivalent circuit of Mode 2

Input voltage source charges Cr , Lr, L_0 and supplies currentto the loads of two CSM boost converters while C_1, C_2 discharges to the loads.

Mode 3: S_0 , S_1 and S_2 are OFF

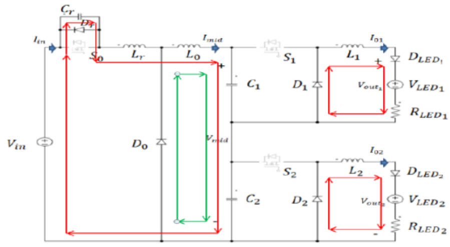

Fig. 4. Equivalent circuit of Mode 3

Input voltage source charges C_r. L_r, $L_0$and supplies current C_1, C_2 and both the capacitors C_1, C_2 are charging. The current of L_1andL_2 are in freewheeling mode.

III.DESIGN METHODOLOGY

The relationship of the output voltage and input voltage in the first stage of converter is given by

$$V_{mid} = D_0 / V_{in} \qquad (2)$$

where Vin is the input voltage of the system, $V_{mid}$is the output voltage of the first stage, and $D_0$is the duty cycle of switch $S_0$of this stage. The relationship of the output voltage $V_{out}$and input voltage V_{mid} in second stage of converter is given by

$$V_{out}/V_{mid} = (1-D)/2D \qquad (3)$$

where and D is the duty cycle of second stage. The relationship between the input current and the outputcurrent of CSM boost converters in the second stage can be expressed as

$$Iout = Imid/D \qquad (4)$$

where I_{mid} is the input current of the second stage, which is also the output current of the first stage. Iout represent the output current of both CSM boost converters; The input voltage is taken as 120V. The switching frequencyis 100 kHz. Output voltage is 23V. output current of the first stage or input current of second stage is taken as 0.7A. The values of inductor is

$L_0 >= (V_{in} * (1 - D) *D)/(2 *I_{mid} * fs)$ …………(5)

Consider the second stage or the low voltage section of the Series Connected Current source Mode Multiple Output

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Converter. Capacitances C1 = C2 = C Assume voltage ripple V_C = 0.1 % of output voltage (V_{out})
C >= (Vin * (1 - D) * D)/ (8 *V_C* L * f_2) …………....(6)
Each CSM boost converter drives an LED. And cut-in voltage V_F is 2.27 V. The resistance $R_d$is empirically found as 2.5. The ripple currents of inductors $I_L$is taken as 40% of the output current I_{out} .D is the duty ratio of both CSM boost converters are equal.
L = ((V_F + I_{out}*R_d)(1 - D))/ Ts* I_L ....(7)
L =((V_F + I_{out}*R_d)(1- D))/(0.4 *I_{out}* f) …………..(8)

IV.SIMULATION RESULTS

Simulation parameters for a series connected current source mode dual output ZVS converter is given in Table below. An input voltage of 120V gives a output voltages of 12V The switches are MOSFET/Diode with constant switching frequency of 100 kHz.

TABLE I
SIMULATION PARAMETER

Parameter	Specification
Input Voltage (V_{in})	120 V
Input Current (I_{mid})	0.7 A
Output Voltage (V_{out})	23 V
Switching Frequency	100 kHz
Inductor L_0	2.38 mH
Inductors L_1, L_2	220 μH
Capacitors C_1 , C_2	50 μF
Resonant Inductor L_r	2.98 μH
Resonant Capacitor C_r	29 nF

A. Simulink model of proposed converter

The series connected current source mode dual output ZVS converter is simulated in MATLAB/SIMULINK by choosing the parameters listed in Table 1 and the Simulink model is shown in figure 5.

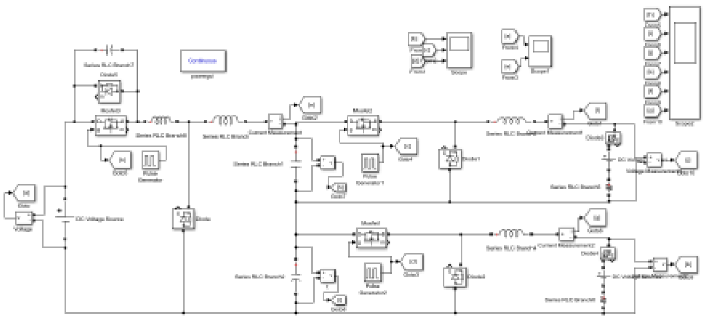

Fig. 5. Simulink Model

B. Simulation Results

The simulation results of the series connected current source mode multiple output converter are shown. It can be seen in fig.6. that the input voltage Vin is 120V. The switching
frequency is chosen to be 100kHz.

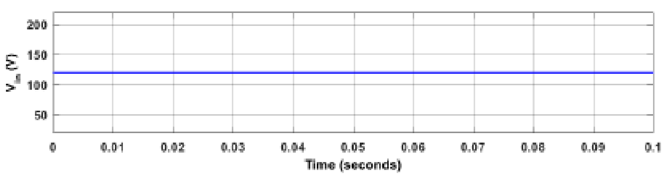

Fig. 6. Waveform of Input Voltage Vin

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As per fig.7. the output voltage $V_{mid}$of first stage is measured as 77.5V and the inductor current or the output current of first stage is I_{mid} is 0.66A and ripple current of 0.05A. Voltage ripple is 0.1V.

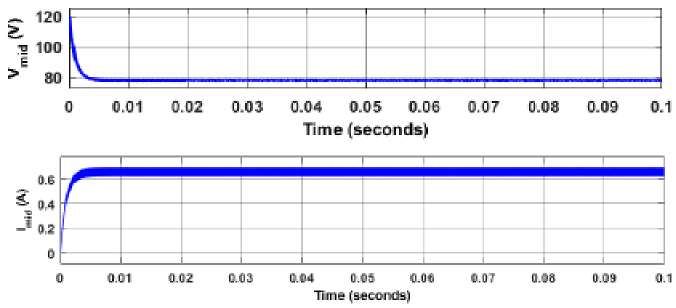

Fig. 7. Waveforms of output voltage $V_{mid}$and of first stage and outputcurrent of first stage I_{mid}

By introducing a zero voltage switching circuit voltage stress across the switch in the first stage can be reduced considerably. The waveforms of switching signal VG0, resonant voltage V_{Cr} and resonant current I_{Lr} is obtained from MATLAB simulation are shown in fig.8.

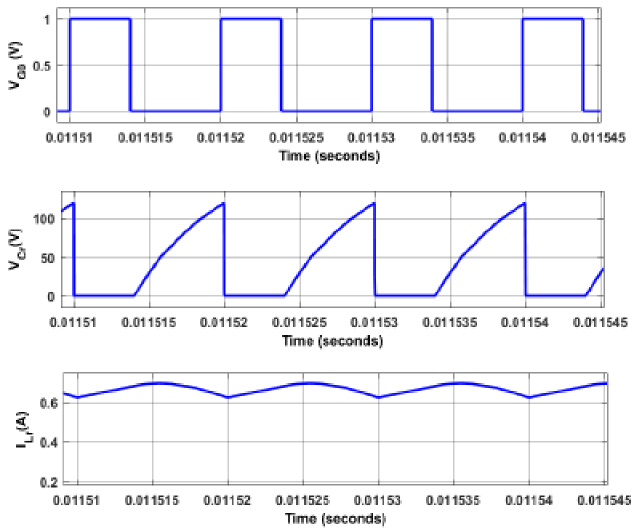

Fig. 8. Waveforms of switching pulse V_{G0}, resonant voltage V_{Cr}, resonant current I_{Lr}

Output voltage V_{01} output current $I_{01}$of the second stage are shown in the fig.9. V_{01} is measured as 23.76V and the ripple voltage is 7.9V. I_{01} is measured as 1.034A with ripple current of 0.4A.Output voltage V_{02} output current I_{21} of the second stage are same as $V_{01}$and I_{01}

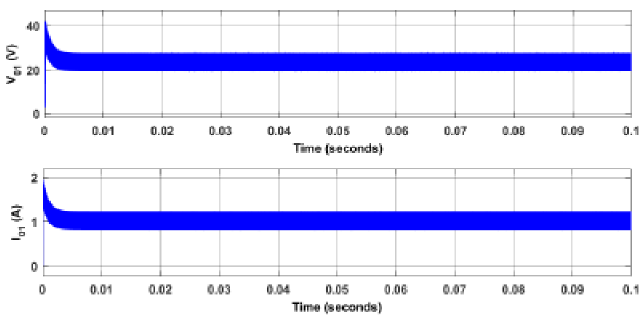

Fig. 9. Waveforms of output voltage V_{01} output current I_{01}

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V. ANALYSIS

Analysis of dual output ZVS converter is carried out by considering parameters like efficiency, voltage gain, ripple voltage and duty cycle.

A. Efficiency Vs Output Power

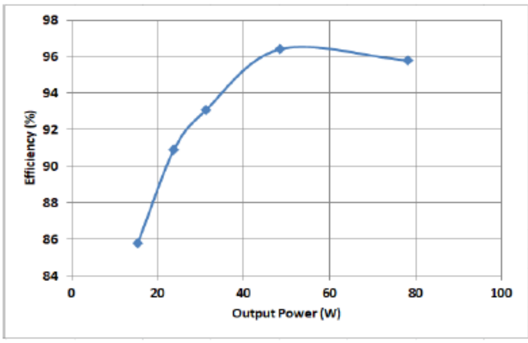

Fig. 10. Efficiency Vs Output Power

Efficiency of a power equipment is defined at any load as the ratio of the power output to the power input. The efficiency tells us the fraction of the input power delivered to the load. The converter efficiency is around 96.409 % for and output power of 48W.

B. Output Voltage Ripple Vs Duty Cycle

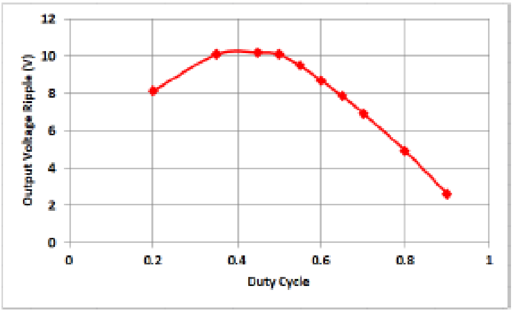

Fig. 11. Output Voltage Ripple Vs Duty Cycle

There is a gradual decrease in the output ripple voltage for increase in the duty cycle. Ripple voltage varies from 10.2V to 2.62V when duty cycle increases from 45% to 90%. But when duty cycle vary from 20% to 45% output ripple voltage increases.

C. Output Ripple Voltage Vs Frequency

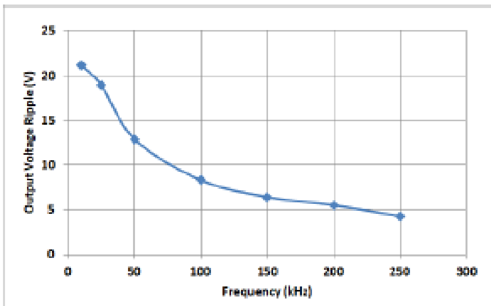

Fig. 12. Output Voltage Ripple Vs Frequency

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Output ripple voltage and switching frequency are inverselyproportional. When the switching frequency increases, ripple voltage reduces. The converter ripple voltage is around 8V for 100kHz .

D. Voltage Gain Vs Duty Cycle

Voltage Gain is defined at any load as the ratio of output voltage to input voltage. Here the voltage gain increases for an increase in the duty cycle of the second stage. The converter gain is varying from 0.08 to 0.23 for varying the duty cycle from 20% to 90%

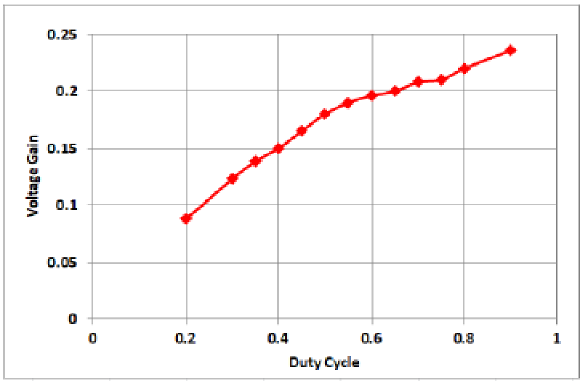

Fig. 13. Voltage Gain Vs Duty Cycle

VI.CONCLUSION

Current-source-mode converters, though being always available for design are still rarely used in power electronics.Power converters with a high step-down ratio are used in a variety of applications where the loads are required to be fed by a low voltage. Current-source-mode converters are two-stage transformerless series connected configuration and

high voltage step-down ratios can be easily realized, due to the zero voltage switching in the first stage of converter, switching losses are reduced leading to voltage stress reduction of switches.Moreover, the control requirement is drastically simplified when connected in series. Specifically, the problems of hard switching converter can be solved by soft switched zero voltage switching configuration.. Design and operation is very flexible.It has high voltage step down ratio. The converter offers low voltage ripple and high efficiency operation. The converter can be used for the application such as Light Emitting Diodes and Battery Chargers.

REFERENCES

[1] Z. Dong, C. K. Tse, and S. Y. R. Hui, Current-source-mode singleinductor multiple-output LED driver with single closed-loop controlachieving independent dimming function, IEEE J. Emerg. Sel. Top. Power Electron., vol. 6, no. 3, pp. 1198-1209, 2018.

[2] Q. Hu and R. Zane, LED driver circuit with series-input-connectedconverter cells operating in continuous conduction mode, IEEE Transactionson Power Electronics,vol. 25, no. 3, pp. 574-582, 2010.

[3] J. W. Kim, J. S. Yon, and B. Cho, Modeling, control, and designof input-series-output-parallel-connected converter for high-speed-trainpower system, IEEE Transactions on Industrial Electronics, vol. 48,no. 3, pp. 536-544, 2001

[4] C. K. Tse, Zero-order switching networks and their applications to powerfactor correction in switching converters, IEEE Transactions on CircuitSystems I: Fundamental Theory Applications, vol. 44, no. 8, pp. 667- 675, 1997

[5] Y. Huang, C. K. Tse, and X. Ruan, General control considerations forinput-series connected DC/DC converters, IEEE Transactions onCircuit Systems I: Reg. Papers,, vol. 54, no. 5, pp. 1099-1108, 2007.

[6] M. Esteki, B. Poorali, E. Adib, and H. Farzanehfard, Interleaved buckconverter with continuous input current, extremely low output currentripple, low switching losses, and improved step-down conversion ratio,IEEE Transactions on Industrial Electronics, vol. 62, no. 8, pp. 4769-4776, 2015.

[7] R. Ayyanar, R. Giri, and N. Mohan, Active input-voltage and loadcurrentsharing in input-series and output-parallel connected modular IEEETransactions on Power Electronics, vol. 19, no. 6, pp. 1462-1473, 2004

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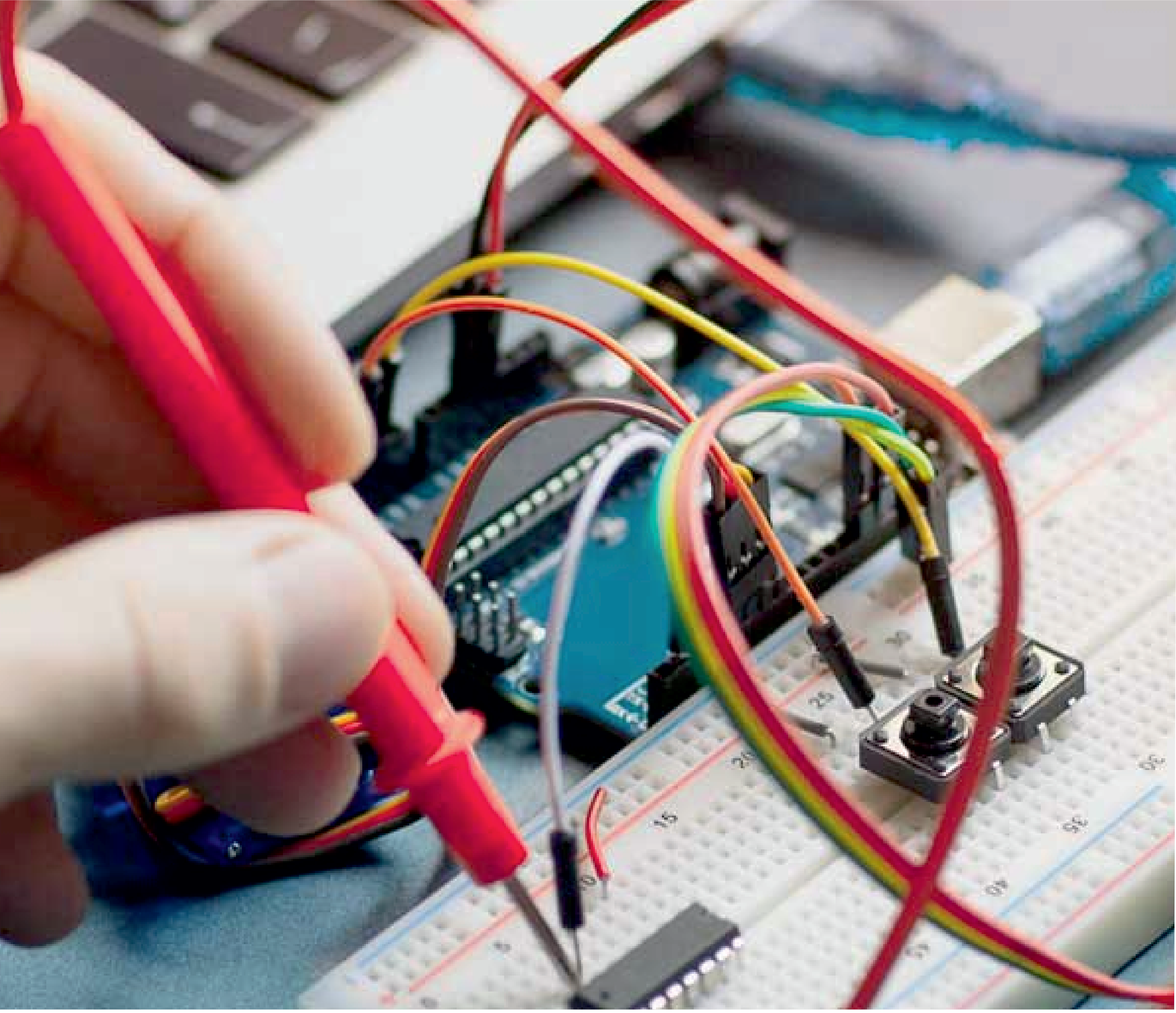
| DOI:10.15662/IJAREEIE.2021.1006034 |

[8] R. Giri, V. Choudhary, R. Ayyanar, and N. Mohan, Common-dutyratiocontrol of input-series connected modular DC-DC converters withactive input voltage and load-current sharing, IEEE Transactions onIndustrial Applications,, vol. 42, no. 4, pp. 1101-1111, 2006.

[9] M. Schweizer and J.W. Kolar, Design and implementation of a highly efficientthree-level T-type converter for low-voltage applications, IEEETransactions on Power Electronics , vol. 28, no. 2, pp. 899-907, 2013.

[10] H. Wu, S. C. Wong, C. K. Tse, S. Y. R. Hui, and Q. Chen, Single-phaseLED drivers with minimal power processing, constant output current,input power factor correction, and without electrolytic capacitor, IEEETransactions on Power Electronics,, vol. 33, no. 7, pp. 6159-6170,2018.

[11] P. Xu, J. Wei, and F. C. Lee, Multiphase coupled-buck converter-a novelhigh efficient 12 V voltage regulator module, IEEE Transactions onPower Electronics,vol. 18, no. 1, pp. 74-82, 2003.



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