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TWO SWITCH MULTIPLE OUTPUT FORWARD CONVERTER INTEGRATED WITH BUCK CONVERTER

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Abstract: Satellite have been widely developed for public missions such as national defense and meteorology. The power capacity of satellites continues to increase. Accordingly, the weight and loss of the electrical power system of the satellite must be reduced. As the power capacity of satellites increases, a high bus voltage is strongly required to reduce the weight and power losses. However, most high-power DC/DC converter topologies such as half-bridge and full-bridge DC/DC converters have leg-structures, which violate the heritage design characteristics of the DC/DC converters for satellites. A DC/DC converter topology suitable for a high bus voltage that satisfies the heritage design characteristics of DC/DC converters for satellites is designed using a two-switch forward converter with an integrated buck converter. Since this converter integrates two DC/DC converters, the number of semiconductor devices is reduced. As a result, its cost, weight, and volume can be greatly reduced. Moreover, the zero-voltage switching of the low-side switch can be achieved and the efficiency is improved. Here, two switch forward converter with integrated buck converter is used to produce three outputs from a single input to use in satellite. The simulation is done in MALTLAB. The effectiveness and feasibility of the converter were verified with a prototype of 100 V input and 100 W (40 V/50 V) output.

***Index Terms* –** Direct Current

I. Introduction

Satellites have been widely developed for public missions such as national defense and meteorology. The satellite comprises a bus and a payload system. The bus system performs fundamental operations, while the payload system performs mission-specific operations. An electrical power system is one of several subsystems constituting a bus system. The electrical power system consists of a folded solar array, Li-ion battery, and a power control distribution unit (PCDU). Various DC/DC converters are used in the electrical power systems of satellites. The DC/DC converter topologies used in satellites have different heritage design characteristics from those of the DC/DC converters used on Earth. The first heritage design is a non-leg-structure DC/DC converter topology. Because bus capacitors and Li-ion battery comprising bus receives significant damage in an arm-short case, a conservative design is essential to guarantee the mission life of the satellite. Therefore, the DC/DC converter directly connected to the bus in the PCDU, the main power unit of the satellite, uses a non-leg-structure topology.

To solve the aforementioned problems, a new DC/DC converter topology suitable for a high bus voltage that satisfies the heritage design characteristics of DC/DC converters for satellites is designed in this paper. The converter has a new structure that integrates the conventional isolated and non-isolated DC/DC converters used in satellite electrical power systems. Since the designed converter integrates two DC/DC converters, the number of semiconductor devices is reduced. Consequently, the cost, weight, and volume are reduced. Moreover, zero-voltage switching (ZVS) of the low-side switch is achieved.

II. Integrated DC-DC Converter

The buck converter in the topology is integrated into the two-switch forward converter. As a switch Q1 and a diode D1 of the buck converter are integrated into the two-switch forward converter, only one passive element, that is, the inductor, is added to implement the buck converter. Therefore, while using a two-switch forward converter suitable for a high bus voltage, the cost, weight, and volume are reduced through the integration of the buck converter. Besides, the integrated buck converter cell helps the ZVS operation of Q2 of the two-switch forward converter, which increases the efficiency. The circuit diagram of the converter is given in the **Fig.1.**

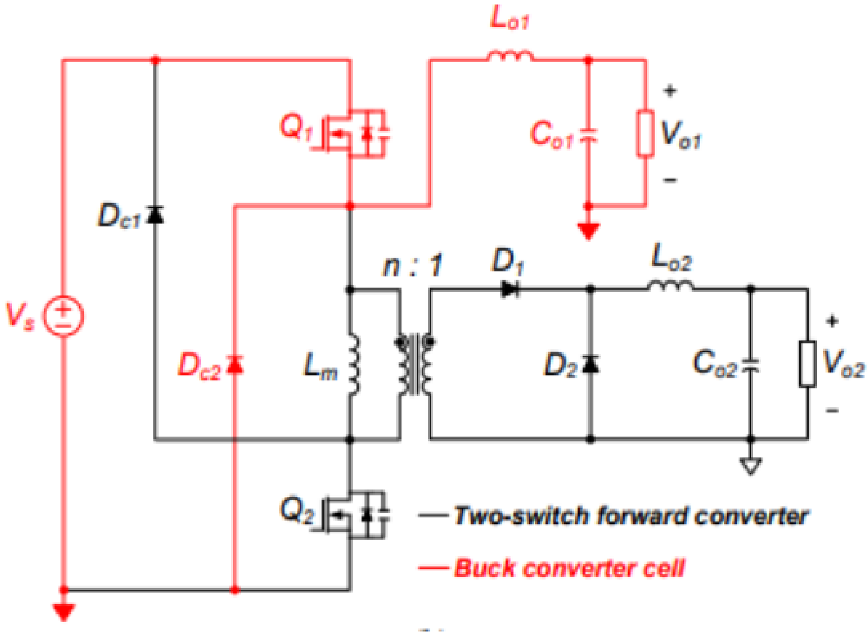

Figure 1 Buck Converter Integrated With Forward Converter

Similar to a conventional buck converter, the converter designed regulates the output of the buck converter by controlling the duty ratio of Q1. In the case of a two-switch forward converter, the output voltage is regulated using the effective duty ratio, which is determined by Q1 and Q2. When Q1 and Q2 are turned on simultaneously, the two-switch forward converter has an effective duty ratio. Therefore, the two-switch forward converter can regulate the output voltage by only controlling Q2. Consequently, in the proposed converter, buck converter is regulated by Q1, and the two-switch forward converter is regulated by Q2. The given converter has five operational modes during the switching period.

Mode 1 begins when Q1 and Q2 are turned ON. Accordingly, Vs is applied to the transformer, and transferred to the secondary side of the transformer as V − s/n. Accordingly, Vs/n−Vo2 is applied to Lo2, and Lo2 builds up the second output current. Subsequently, Vs−Vo1 is applied to Lo1, and Lo1 builds up the first output current. Mode 2 begins when Q2 is turned OFF, Q1 is in the ON state, and D −c1 is conducted. When Q2 is turned OFF, the current flows through the output capacitor of Q2. Consequently, Vs is applied to Q2, and VLm is clamped to zero. Vs − Vo1 is applied to Lo1, and −Vo2 is applied to Lo2. Mode 3 begins when Q1 is turned OFF, and D2, Dc1, and Dc2 are conducted. When Q1 is turned OFF, the current flows through the output capacitor of Q1. Consequently, Vs is applied to Q1, VLm is clamped, −Vs. −Vo1 is applied to Lo1, and −Vo2 is applied to Lo2. Mode 4 begins when iLm reaches zero. As iLm reaches zero and Dc2 is conducted as the rectifier diode of the buck converter, VLm starts to decrease. Moreover, the output capacitor of Q2 and the parasitic capacitor of Dc1 begin discharging. As the output capacitor of Q2 is discharged during mode 4, ZVS of Q2 can be achieved.−Vo1 is applied to Lo1, and −Vo2 is applied to Lo2. Mode 5 begins when VQ2 and VLm reach zero. As VLm reaches zero, iLm remains constant, and iP ri remains zero. −Vo1 is applied to Lo1, and −Vo2 is applied to Lo2.

III. Multiple Output DC-DC Converter

The modified version of dc-dc converter uses a two switch forward converter circuit and a buck converter circuit together to get three output from one input.Multiple output is obtained by tapping the secondary side of the transformer in the forward converter. A non-isolated outptu is obtained from the buck converter and two isolated outputs are obtained from the forward converter, hence the three outputs are obtained. The buck converter consist of a switch, a diode and a load circuit. The two-switch forward converter consist of two switches, six diodes, a transformer and two load circuits. As a switch and a diode of the buck converter are integrated into the two-switch forward converter, only one passive element, that is, the inductor, is added to implement the buck converter. This design gives a multiple output DC-DC converter with less number semiconductor devices and less losses. The diagram of the multiple output DC-DC converter is shown in **Fig 2**.

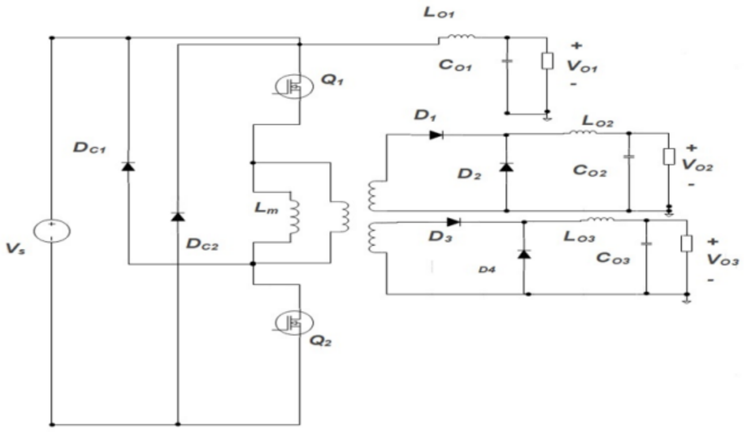

Figure 2 Multiple Output DC-DCConverter

IV. Design of Components

Take, input voltage as 100V, power as 100W, maximum input votage as 120V, minimum input voltage as 80V, maximum input current as 2A, minimum input current as 0.2A and frequency as 50 KHz. For buck converter take output voltage as 50V and for forward converter output voltage as 40V.

4.1Duty Ratio

$$D1 = Vo1/Vsmax \quad (1)$$
$$D1 = 50/120 \quad (2)$$
$$D1 = 0.4 = 40\% \quad (3)$$

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$$D2 = Vo2/Vsmax \quad (4)$$
$$D2 = 40/120 \quad (5)$$
$$D2 = 0.3 = 33.3\% \quad (6)$$

Set the duty ratio as 0.4 for the buck converter and 0.33 for the forward converter.

4.2 Inductors

$$Lo1 = (Vo(D))/(Iomin * 2f) \quad (7)$$
$$Lo1 = (50 * (10.4))/(0.2 * 2 * 50 * 1000) \quad (8)$$
$$Lo1 = 1.5 * 10{-}3H \quad (9)$$

$$Lo2, Lo3 = (Vo2(D))/(Iomin * 2f) \quad (10)$$
$$Lo2, Lo3 = (50 * (10.33))/(0.2 * 2 * 50 * 1000) \quad (11)$$
$$Lo2, Lo3 = 1 * 10{-}3H \quad (12)$$

Choose inductance as 1.5mH for the inductor of buck converter and 1mH for the two inductors of forward converter.

4.3 Capacitors

$$Co1 = D1/(8Lo1 * f\ 2 * \%Vo) \quad (13)$$
$$Co1 = 0.4/(8 * 1 * 103 * (50 * 103\ )\ 2 * 6 * 10{-}3\ ) \quad (14)$$
$$Co1 = 100\mu F \quad (15)$$

$$Co2, Co3 = D2/(8Lo2 * f\ 2 * \%V0) \quad (19)$$
$$Co2, Co3 = 0.33/(8 * 1 * 103 * (50 * 103\ )\ 2 * 6.7 * 10{-}3\ ) \quad (20)$$
$$Co2, Co3 = 100\mu F \quad (21)$$

Choose the value of capacitor as 100 µF for buck converter and 100µF for the two capacitors of the forward converter.

V. Simulation of Multiple Output DC-DC Converter

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy way to use environment where problems and solutions are expressed in familiar mathematical notation. SIMULINK is a software package for modelling, simulating, and analysing dynamical systems.
The buck converter integrated with two switch forward converter is simulated in MATLAB/SIMULINK and the Simulink model is shown in **Fig 3.**

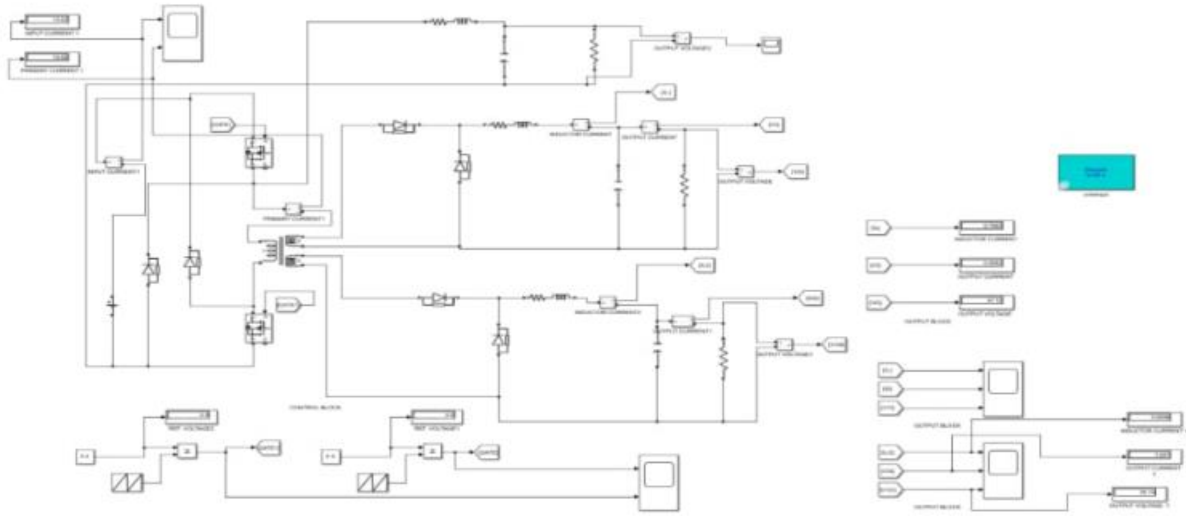

FIGURE 3 SIMULINK MODEL OF DC-DC CONVERTER

Output voltages from the buck converter and forward converter are obtained after simulation. There are three output voltages, one from the buck converter (non-isolated part of circuit) and two from forward converter (isolated part of circuit) The output voltage Vo1 from the buck converter is 65V and is given in **Fig 3**.

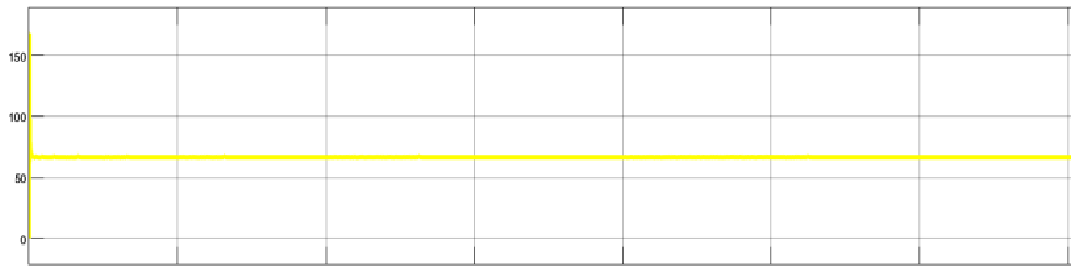

FIGURE 4 OUTPUT VOLTAGE OF BUCK CONVERTER

The first output voltage Vo2 from the forward converter is 50V and is given in **Fig 4**.

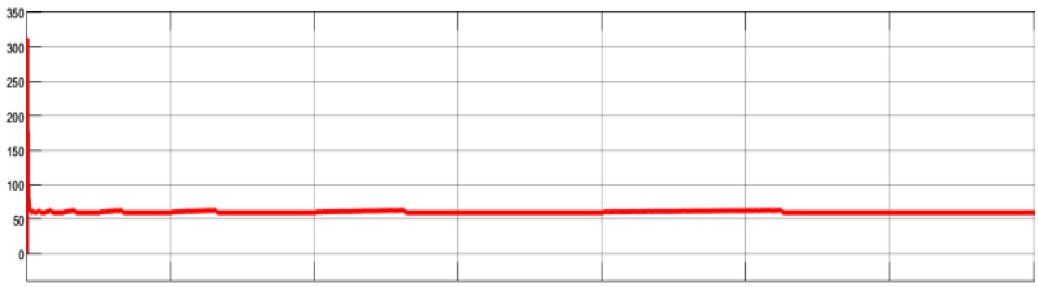

FIGURE 5 FIRST OUTPUT VOLTAGE OF FORWARD CONVERTER

The second output voltage Vo3 from the forward converter is 40V and is given in **Fig 6.**

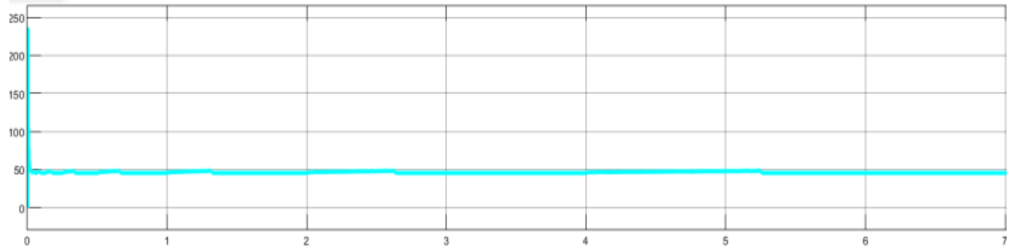

FIGURE 6 SECOND OUTPUT VOLTAGE OF FORWARD CONVERTER

VI. Theoretical framework

The effectiveness and feasibility of the converter is studied at 100/130 V input and 100 W and 40 V/50 V output. This converter uses fewer semiconductor devices because the switch and diode of the buck converter are integrated into the two-switch forward converter. The block diagram is shown in **Fig 7**.

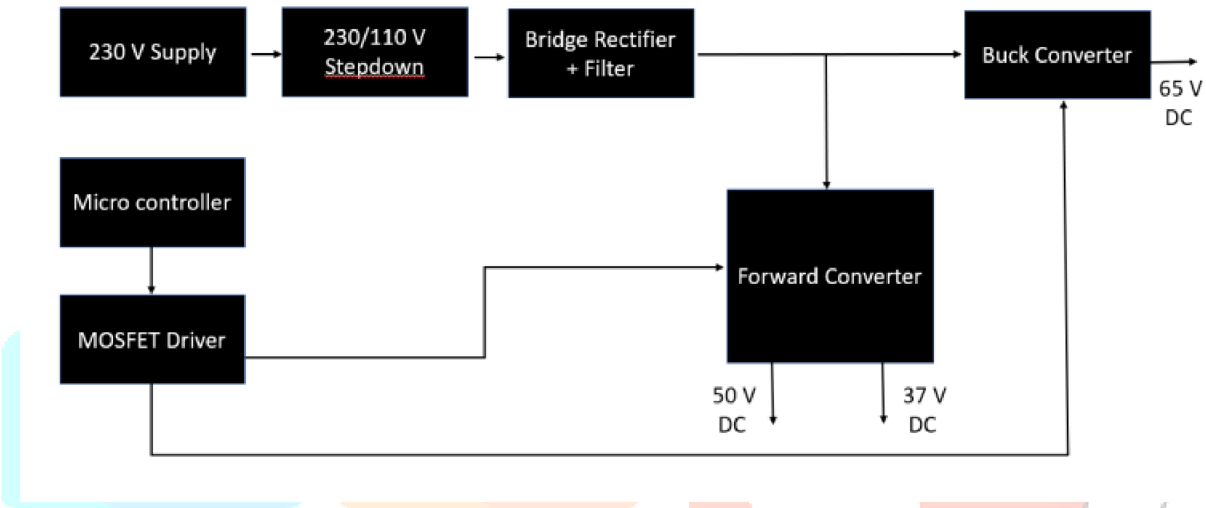

FIGURE 7 BLOCK DIAGRAM FOR HARDWARE IMPLEMENTATION

It consist of control circuit, driver circuit and power circuit. Control circuit is composed of Atmega16 and its power supply. The control pulse for switch is generated using Atmega16 microcontroller. The pulse from microcontroller is amplified by driver circuit which is composed of TLP250H. It also provides isolation between control and power circuits. The power circuit consist of a buck converter and forward converter which are integrated together. The forward converter has two outputs. The complete setup of the experiment is shown in the **Fig 8**. The setup include control circuit,driver circuit,power circuit and digital oscilloscope.

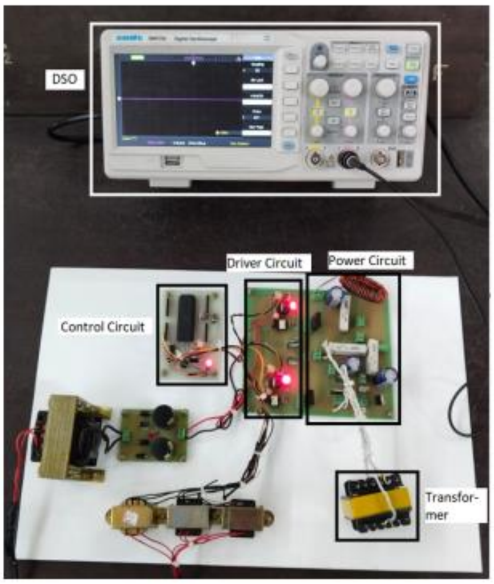

FIGURE 8 HARDWARE IMPLEMENTATION

The experimental model of the two switch multiple output forward converter integrated with buck converter was success in operating five modes of operation.The output waveform from the prototype is given in the figures. The **Fig 9** shows the non-isolated output from the converter which is about 65V.

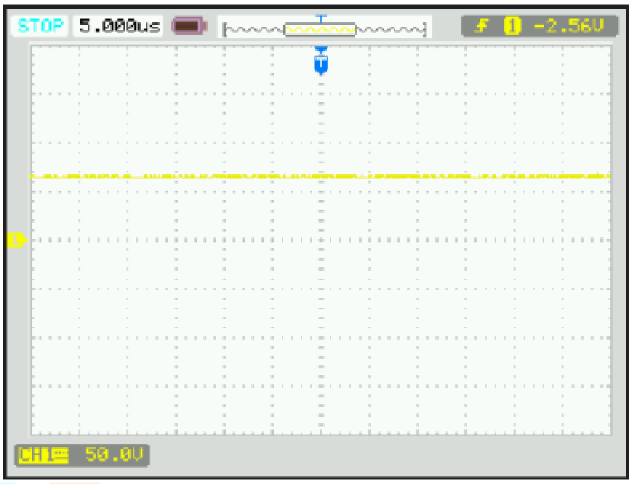

FIGURE 9 OUTPUT VOLTAGE OF BUCK CONVERTER

The **Fig 10** shows the first isolated output from the converter which is about 36V.

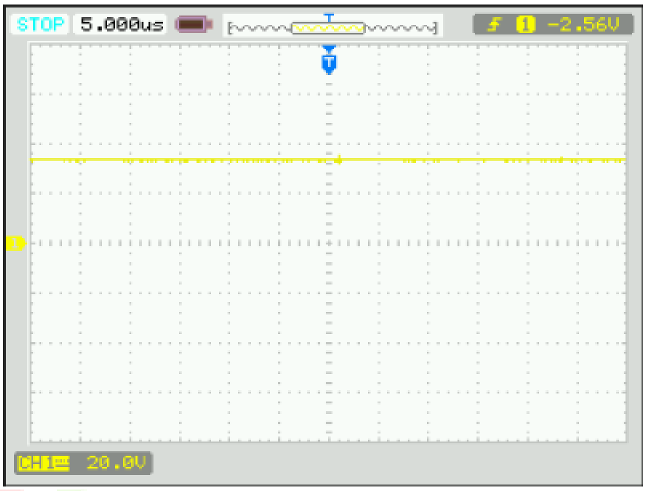

FIGURE 10 FIRST OUTPUT VOLTAGE OF FORWARD CONVERTER

The **Fig 11** shows the second isolated output from the converter which is about 50V.

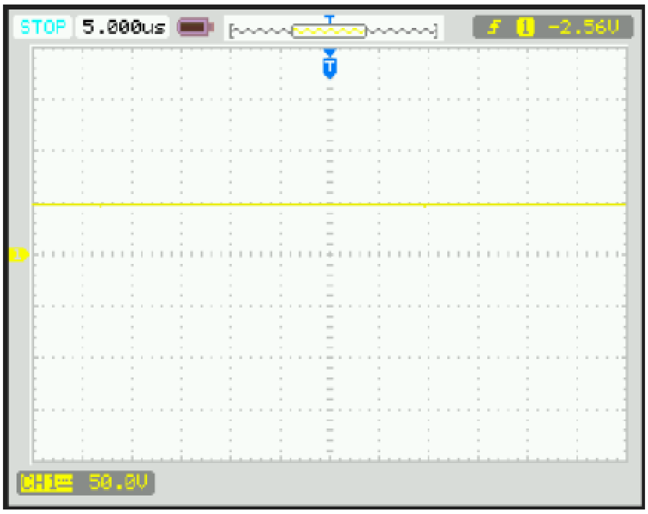

FIGURE 11 SECOND OUTPUT VOLTAGE OF FORWARD CONVERTER

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