https://doi.org/10.51459/futajeet.2021.15.1.311

Journal of Engineering and Engineering Technology

IMPLEMENTION OF A DSPACE CONTROL SYSTEM FOR A NON-ISOLATED DC-DC BOOST CONVERTER

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ARTICLE HISTORY

Received: 02-03-21

Accepted: 22-03-21

KEYWORDS:

Boost converter, DSPACE control system; PI controller.

ABSTRACT

This paper presents the use of the dSPACE rapid control prototype (RCP) control system to implement a feedback control system for a conventional Boost DC-DC converter hardware to validate the converter's operation and performance during the research and development stage. The proposed system was implemented and tested using a conventional Boost DC-DC converter and a dSPACE (RCP) based control strategy. The advantage of employing this control platform for the converter is that it allows for the identification of design errors in the development process without the requirement for complicated control coding. Details of the DC-DC boost converter operations, the converter feedback dSPACE control system experimental setup and experimental test results are all presented in the paper. The results show that the system can conform to any set desired reference voltage.

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1.0 INTRODUCTION

DC-DC converters are electronic devices used when changing direct current (DC) electrical power efficiently from one voltage level to another. DC-DC devices are needed in power electronics because, unlike alternating current (AC), DC cannot be stepped down or up using a transformer. This is important because of the necessity of converting unregulated DC input voltage into regulated DC output voltage in many industrial applications.

There are two different types of DC-DC converters, isolated converters and non-isolated converters. An isolated DC-DC converter uses a transformer to eliminate the DC path between its input and output. In contrast, a non-isolated DC-DC converter has a DC path between its input and output (Taghvaee *et al*, 2013; Grbovic, 2014). Each of which tends to be more suitable for some types of application than for others (Jeremy *et al*, 2020; Raghavendra *et al*, 2019; Abdelsalam and Kamil, 2019). The non-isolated converters are widely used in applications where the step-up or step-down ratio is small and when the input and output can share a supply terminal. DC-DC

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converters can have two distinct modes of operation: continuous conduction mode (CCM) and discontinuous conduction mode (DCM) (Khader, 2011). Essentially, when the inductor current is always non-zero the converter is said to be in CCM and when the current drops to zero during a part of a switching cycle the converter is said to be in DCM.

In practice, a converter may operate in both modes, which have significantly different characteristics. Therefore, a converter and its control should be designed based on both modes of operation (Taghvaee *et al*. 2013; Mohan *et al*. 2003).

One of the major challenges of converters during the research and developmental stage is controlling the converters to adhere to the system desired reference voltage. Hence, this paper proposes the use of a dSPACE (RCP) rapid control prototype system to implement a feedback control system for a conventional Boost DC-DC converter hardware to validate the converter's operation and performance during the research and development stage. The advantage of employing dSPACE RCP system is that it provides a PC-based real-time control platform. This allows for the fast implementation of control algorithms in a real-time environment developed within MATLAB Simulink and enables the identification of design errors in the development process without the requirement for complex control coding.

2.0 BOOST CONVERTER

The boost converter also known as (step-up converter) is a non-isolated DC-DC converter. Its main application is in regulated DC supplies and the regenerative braking of DC motors. As the name implies, the output voltage is always greater than the input voltage (Mohan *et al*. 2003; Varshney *et al*. 2014).

Figure 1 is a conventional DC-DC boost converter that consists of an inductor, diode, switch and a capacitor which is configured in parallel to a resistive load. When the switch is turned on, the diode is reverse biased and isolates the output stage. The input voltage of a boost converter running in steady-state continuous conduction mode (CCM) is stepped up based on (1). Where V_{out} represents the output voltage of the boost converter, D is the duty cycle and V_{dc} is the input voltage.

$$V_{out} = \frac{1}{1-D} V_{dc} \quad (1)$$

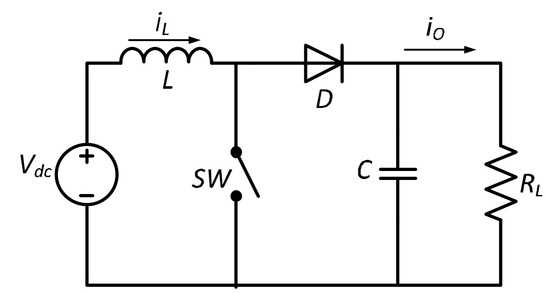

Figure 1: Schematic diagram of a Boost converter

A. Boost converter operation

The configuration of the boost converter circuit during switch ON and OFF interval can be seen in Figure 2 (a) and (b) respectively. Whenever the switch is turned ON,($0 \leq t < t_{on}$), the inductor, *L*, is directly connected to the input voltage source. Consequently, in this scenario I_L rises charging L and it is storing energy from V_{dc} while the diode is reverse biased as a result disconnecting the R_L and C from V_{dc} . All through this interval, the pre-

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charged C ensures a constant voltage across the R_L terminals (Mohan *et al*. 2003; Mohamed and Mohamed, 2010; Bae *et al*, 2013).

However, once the switch is turned OFF ($t_{on} \leq t < T_s$) where T_s is the switching period in this scenario both V_{dc} and the charged inductor are connected to R_L and the diode is forward biased. Figure 2 also shows boost converter steady-state waveforms. Under CCM operation the inductors current flows continuously, (I_L (t) > 0). The time integral of the inductor voltage over a one-time period must be zero when in steady-state (Khader, 2011; Mohan *et al*, 2003). This is depicted in (2).

$$V_{dc}t_{on} + (V_{dc} - V_{out})t_{off} = 0$$

then

$$V_{out} = \frac{T_S}{t_{off}} V_{dc}; D \rangle 0 \qquad (2)$$

Where V_{dc} is the input voltage, t_{on} is the switching-on time, V_{out} is the output voltage, T_s is the switching period and t_{off} is the switching-off time, respectively.

Dividing both sides by T_s and rearranging terms will yield to (3)

$$\frac{V_{out}}{V_{dc}} = \frac{T_S}{t_{off}} = \frac{1}{1-D} \qquad (3)$$

3.0 DC-DC BOOST CONVERTER DSPACE FEEDBACK CONTROL SYSTEM EXPERIMENTAL SETUP

The proposed block diagram of a non-isolated dc-dc boost converter implementing DSPACE control system is depicted in Figure 3. The design consists of a DC power supply source

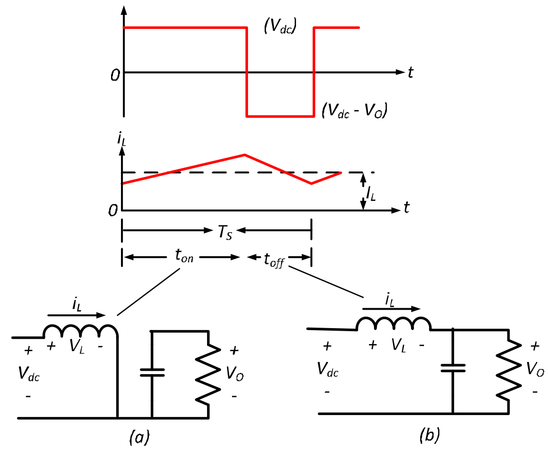

Figure 2: Boost converter CCM: (a) switch ON; (b) switch OFF

HMC 8042 which serves as the power supply to the boost converter. The boost converter is the power electronics part of the system which is connected between the power supply source and the electronic load PLZ1003WH. As earlier stated in (II), the boost converter is a non-isolated DC-DC converter with output voltage always greater than the input voltage. The electrical parameters of the proposed boost converter are presented in Table 1. The aim of designing the boost converter is to step-up the 12 V power supply from the input DC power supply source HMC 8042 to an output voltage of 24 V.

Table 1: Boost converter component specification

Component	Value
Inductor (*L*)	100µH
Capacitor (*C*)	220 µF
Frequency (F_{SW})	20kHz
Resistive Load (R_L)	50Ω
Gate driver	IR4427
MOSFET	FCP 22N60N
Diode	D12560C
Voltage divider	100K & 2K Resistor
Feedback controller	DSPACE (DS4002) Digital I/0

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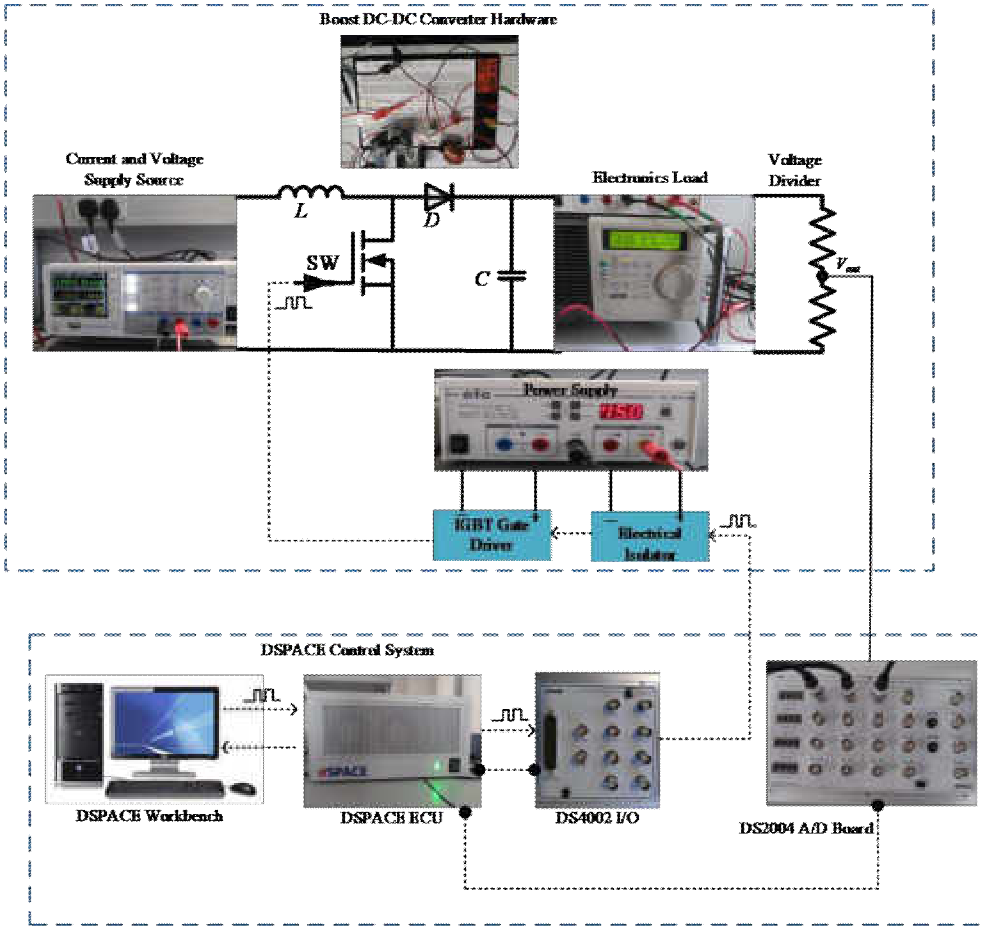

Figure 3: Boost converter DSPACE control system block diagram

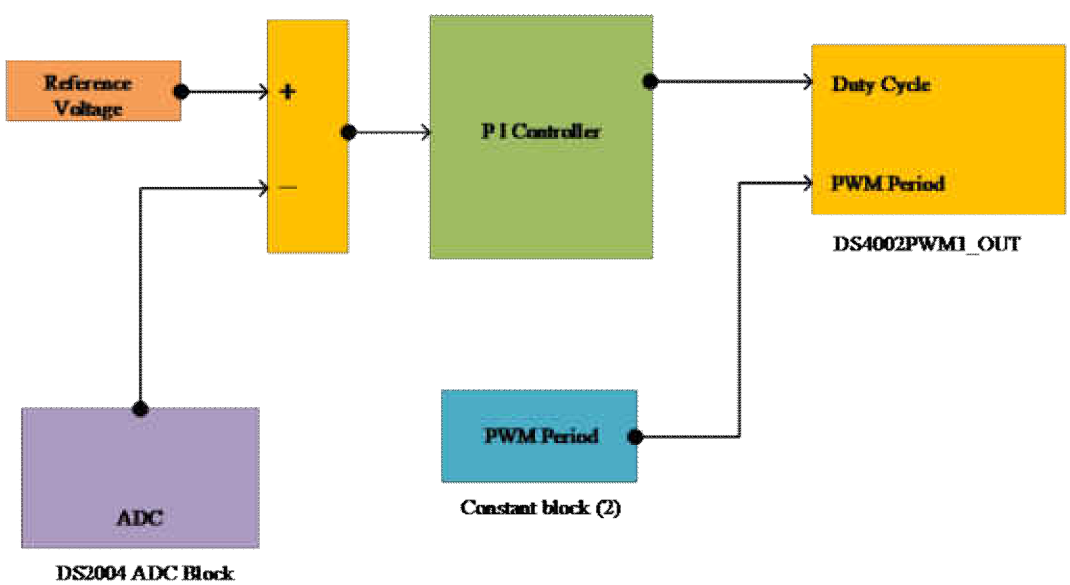

Figure 4: Proportional and Integral Controller (PI)

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The 24 V output voltage of the DC-DC boost converter is scaled down using a voltage divider, as shown in Figure 3, and then fed into the analogue to digital converter (DS2004 ADC) block of the DSPACE control system to be used in the Proportional and Integral (PI) controller as shown in Figure 4. The output voltage is scaled down because the signal applied to a dSPACE ADC channel must be in the range of −10V to +10V.

The output signal of the PI controller is then applied to DS4002PWM1_OUT which is used in generating the required switching signal needed to drive the MOSFET. Controlling DC-DC converters can be achieved using different control methods with each method having its advantages and disadvantages. However, the Proportional and Integral control method was implemented in this system due to its capability of controlling the output voltage with a desirable dynamic response which is suitable for the boost DC-DC converter.

Nonetheless, in Figure 3, it can be seen that the generated PWM signal from the DSPACE control system is connected to an electrical isolator 6N137 Optocoupler and the output of the Optocoupler is then fed to the gate drive of the boost converter to manage the switch ON-time and switch-OFF time of the Boost converter.

4.0. EXPERIMENTAL RESULTS

The proposed DC-DC Boost converter system was tested under open-loop and closed-loop feedback system. However, for this paper a close loop system was implemented to achieve and maintain the desired output condition of the boost converter design with a reference voltage of 24.

Under open-loop conditions, the system could

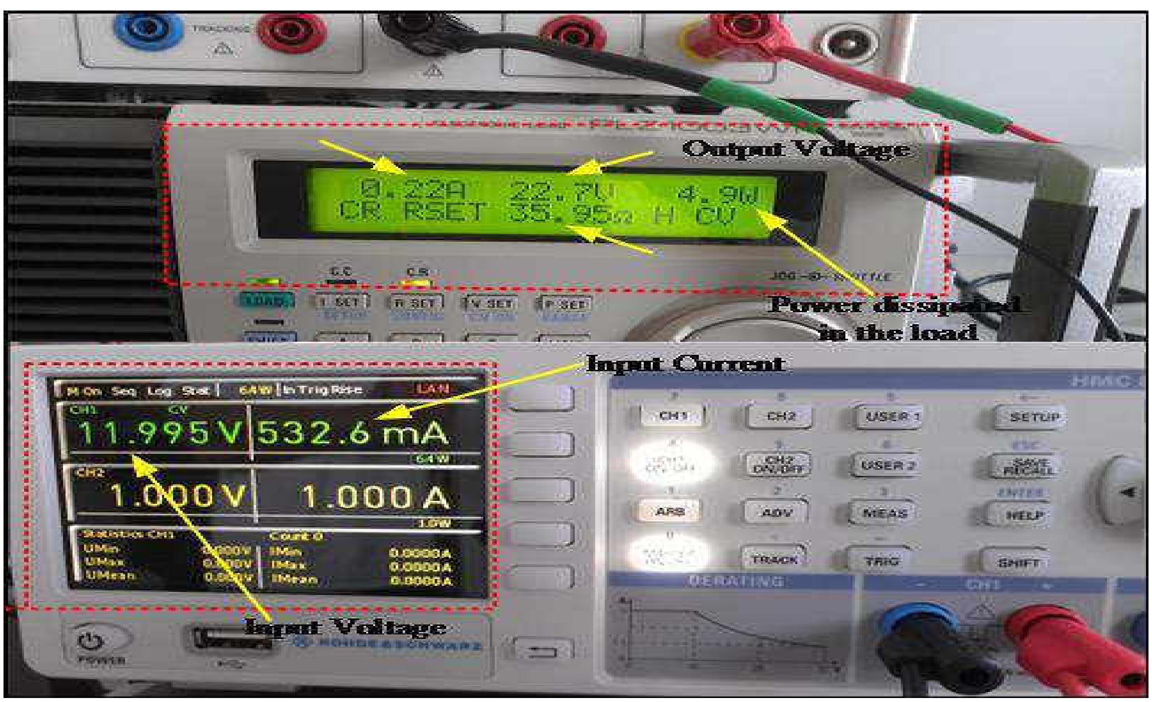

Figure 5: Input and output voltage of the DC-DC Boost converter system under open-loop test condition.

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not achieve the desired reference output voltage of 24 V, as shown in Figs. 5 and 6, respectively. The output voltage of the DC-DC boost converter under this scenario was 22.7 V. However, when the DC-DC Boost converter was tested under closed-loop system using a feedback controller, the output voltage was able to conform to the set desired reference voltage of 24 V as shown in Figure 7 and 8, respectively.

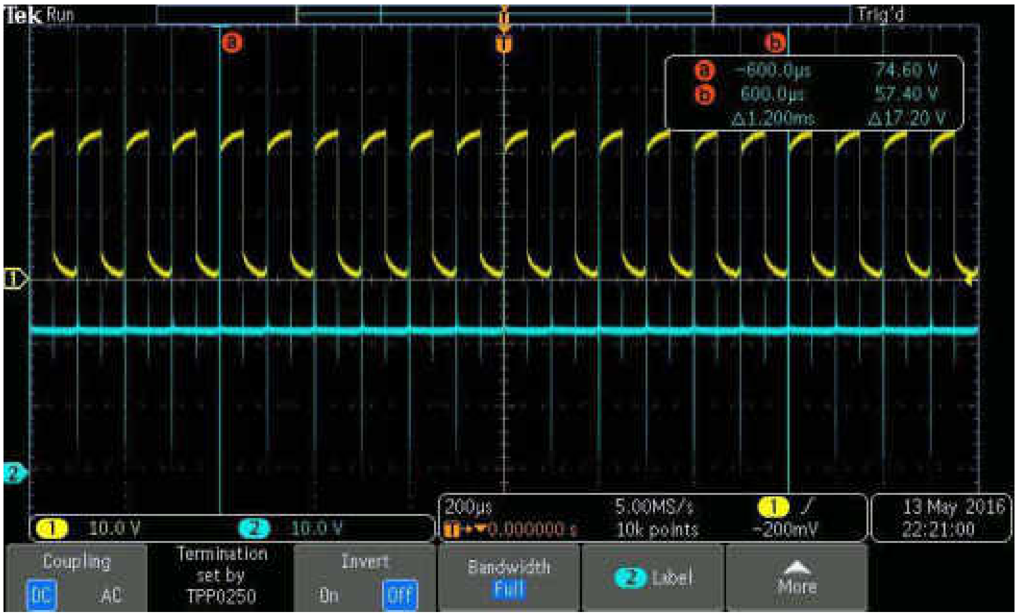

Figure 6: Voltage across switching device and output voltage of the DC-DC converter system under open-loop test condition.

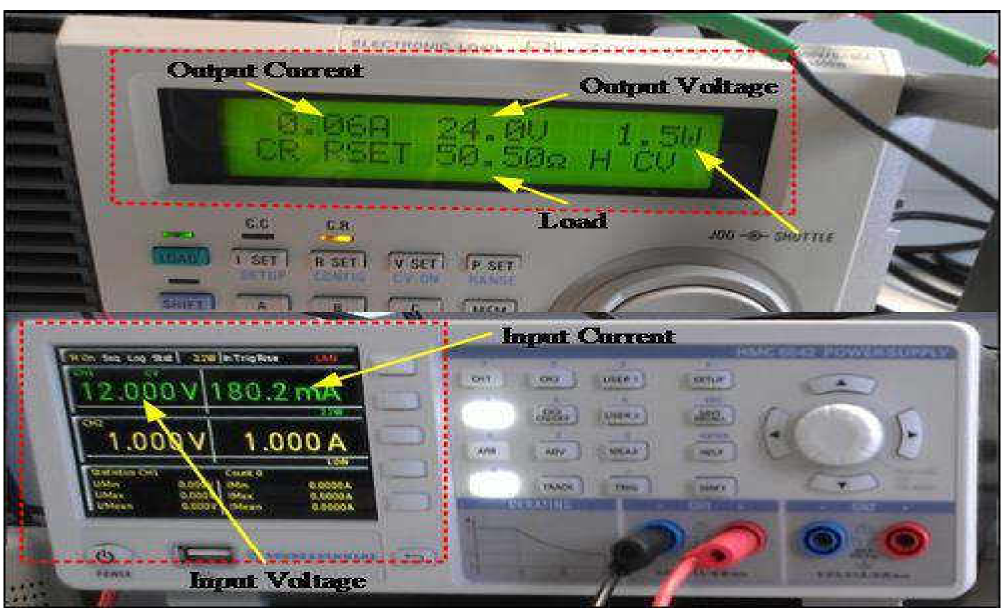

Figure 7: Input and output voltage of the DC-DC Boost converter system under closed-loop test condition.

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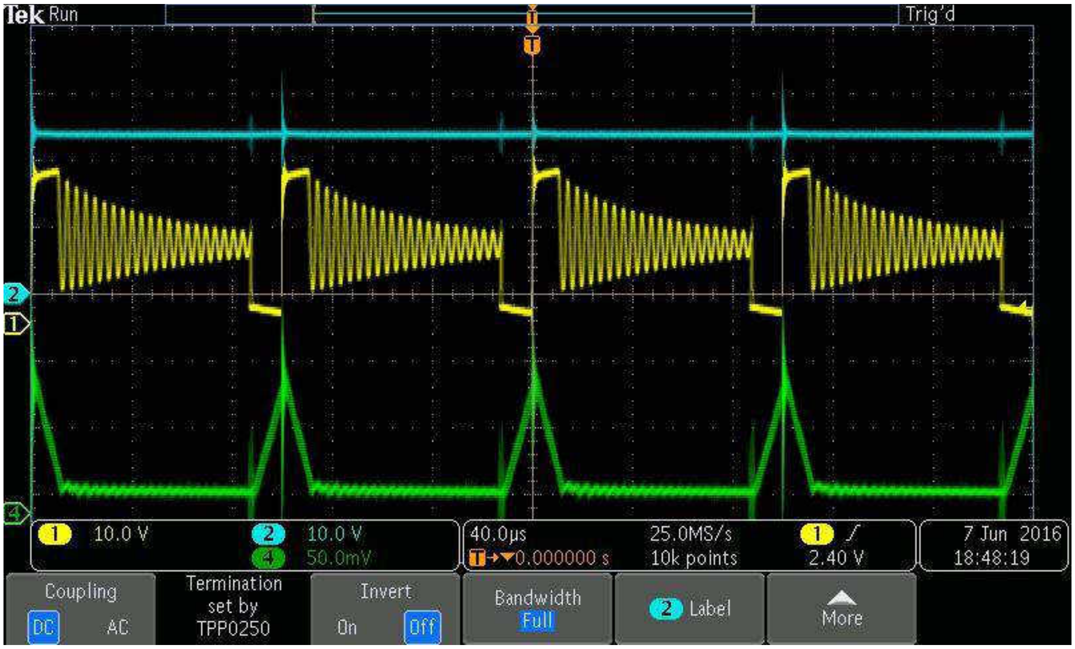

Figure 8: Result of the DC-DC Boost converter under closed-loop feedback test condition. The output voltage (blue trace), voltage across switching device (yellow trace) and inductor current (green trace) of the DC-DC Boost converter under closed-loop test condition.

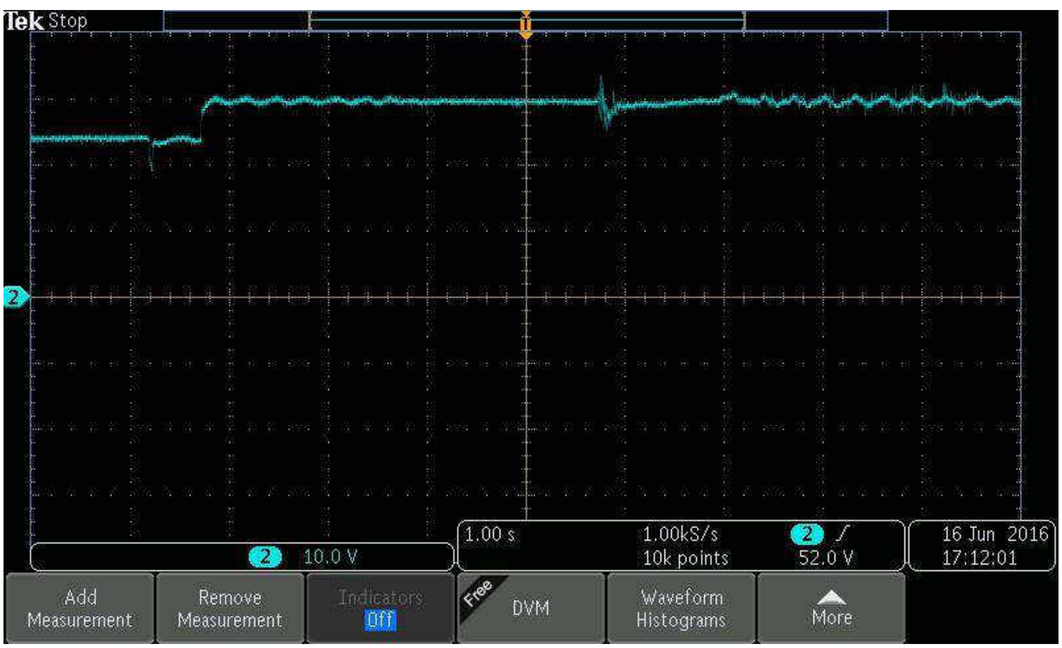

Figure 9: DC output voltage step change from 24 V to 30V

Further tests were carried out to test the system performance under closed-loop feedback system by varying the system desired reference output voltage for step changes from 24 V to 30 V and 30 V to 24 V as shown in Figures 9 and 10.

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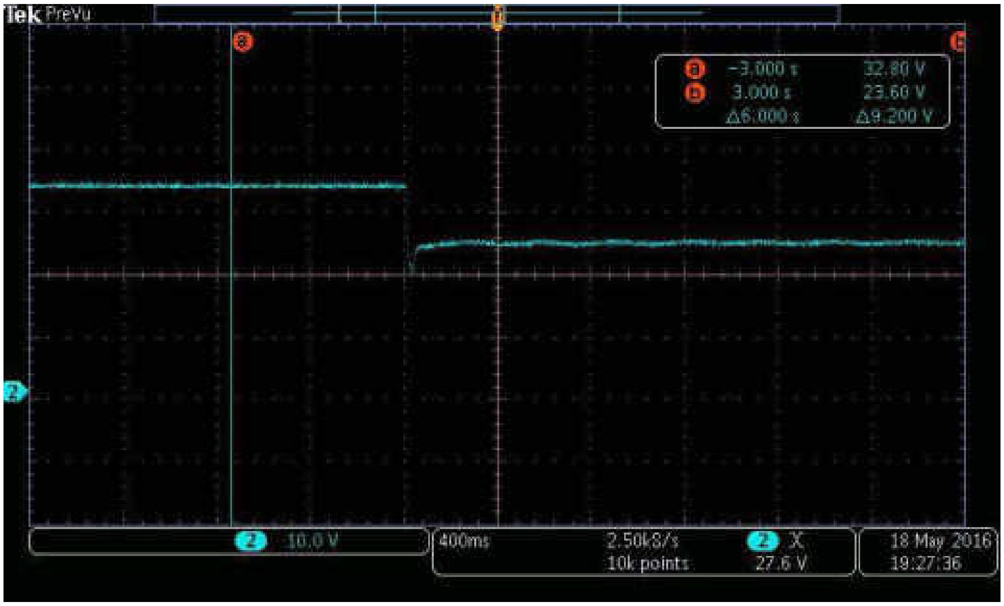

Figure 10: DC output voltage step change from 30 V to 24 V

5.0 CONCLUSION

In this paper, the dSPACE (RCP) feedback control system for a conventional Boost DC-DC converter hardware was proposed to validate the converter's operation and performance during research and development stage. The proposed DC-DC Boost converter test result under closed-loop system using the dSPACE feedback controller system can control the output voltage to conform to any set desired reference voltage even with step changes in the input voltage of the converter. The experimental results show that the dSPACE-based control system is effective in controlling the operation and performance of a converter in real-time.

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