

RESEARCH ARTICLE

Design of Voltage Transducer for Digital Signal Processing Development Kit in Implementation of a High Step-up DC-DC Converter

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ABSTRACT

High step-up DC-DC converters are used in many industrial applications. Especially, renewable energy systems that have a low output voltage and high output current need DC-DC converters with high voltage gain to meet the requirements of the grid-connected systems for a high output voltage. This study is aimed to design an implementation of hardware of the high step-up DC-DC converter's measurement board prototype for digital signal processing (DSP) TMS320F28335 development kits. The vital parameter to detect for high step-up application systems is a sampling output voltage. This sample of output voltage is produced by using the voltage transducer (LV 25-P) with hall effect sensor in this research. A signal conditioning circuit includes an operational amplifier featuring unity gain buffer for the protection ADC of the DSP and a low pass filter circuit. Therefore, the requirements of the ADC of EZDSP TMS320F28335 development kit can be met by using this voltage transducer sensor and the signal conditioning circuit.

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1. Introduction

Recently, photovoltaic (PV) sources adopted for DC power generator in a micro grid system as one of the next-generation of power systems have been receiving attention due to the self-sufficient in small areas (Eghtedarpour & Farjah, 2014; Carrasco et al., 2006; Lakshmi & Hemamalini, 2017; Lee & Do, 2018). Due to this power source introduce a very low voltage, a high step-up converter is required. A conventional boost converter is not a convenient option to ensure such a high voltage gain because of the low system efficiency. So, a lot of high step-up DC-DC converters with different control

techniques in literature are proposed to introduce a high voltage gain (Genc & Koc, 2017; Goudarzian et al., 2020; Rezvanyvardom & Mirzaei, 2020; Hariri et al., 2021; Koç et al., 2022; Asl et al., 2023; Pandey & Pattnaik, 2023; Varesi & Rouin, 2023). Above mentioned issues about conventional boost converter, Huber and Jovanovic (2000) introduces two series cascaded conventional boost converters for high step-up applications. However, the topology with cascaded conventional boost converter in Huber and Jovanovic (2000) has disadvantages like complex, bulky circuit, and stability problems. So, the compact topologies with one active switch are proposed in Asl et al. (2023), Varesi and Rouin (2023), and

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Pandey and Pattnaik (2023). These cascade boost converters with one active switch allow a convenience for the control strategy of the converter.

One of the main problems for PV sources is to provide good quality of the power to grid system. Therefore, measuring of the parameters of the power system, monitoring by detecting electrical disturbance such as voltage sag or swell, transients and fluctuations and ensuring real-time data for controller is important in the power system. A well measurement of power devices requires to be able to work with perfect accuracy and to eliminate the external interference (Hariri et al., 2021).

This study is aimed to design a measurement board prototype of the high step-up DC-DC converter which includes a voltage sensor and a signal conditioning circuit. In this measurement board prototype, high quality voltage sensor ensures a precise result to the controller. A digital signal processing (eZdsp TMS320F28335) development kit is used as controller. This controller board was used for traditional PI controller to regulate the output voltage of the high step-up DC-DC converter.

In section 2, sampling circuit, voltage transducer circuit and signal conditioning circuit are introduced for cascade boost converter with soft switching performance. Experimental results and discussion are introduced in section 3, respectively.

2. Materials and Methods

High step-up converters due to the low DC output voltage of PV systems is quite needed. To obtain such a high output voltage, some voltage gain technique are used. One of this technique is cascade quadratic boost converter in which two boost converter is associated by using only one main active switch. Cascade boost converter has a high voltage gain because of the quadratic structure but a low conversion efficiency (Koç et al., 2022). An active soft switching technique is applied to the converter to obtain a zero voltage switching (ZVT) performance as shown in Figure 1 (Genc & Koc, 2017). Therefore, this introduces to the converter a high performance and efficiency. In Figure 1 Power circuit, voltage sampling circuit, TMS320F28335 eZdsp controller unit, a drive circuit can be seen.

High step-up converter's output voltage parameter should be continuously monitored and controlled to keep it a constant voltage. As mentioned above, sensor play an important role to stabilize output voltage of DC-DC converter in a PV systems application. Hence, measuring correctly output voltage parameter for the closed loop voltage controller is crucial.

In this study, the LV 25-p voltage transducer from LEM is used due to perfect accuracy, a successful linearization, extensive bandwidth and elimination of the external interference.

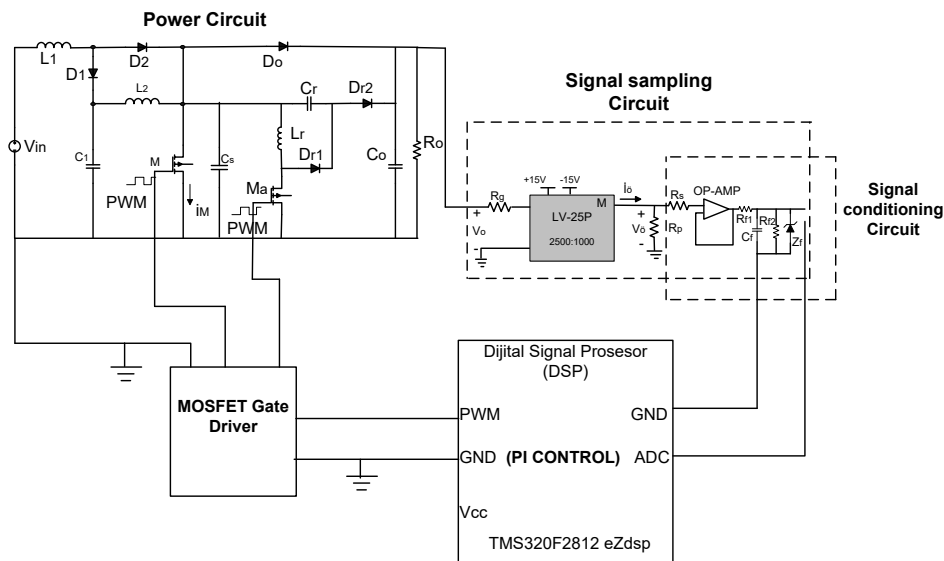


Figure 1. Digital control of the DC-DC converter with LV 25-p voltage sensor and signal conditioning circuit.

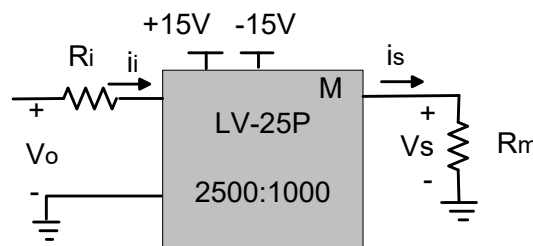


Figure 2. LV 25-p voltage transducer circuit diagram.

Primary side nominal RMS current of this voltage transducer is 10 mA whereas the voltage of the primary side is suitable for measuring a nominal voltage level from 10 V and up to 500V. So, 10 mA is referenced for primary nominal RMS current. Output voltage parameter (V_o) of the DC-DC converter was designed as 300 V. In Figure 2 R_i and R_m are input resistance and measuring resistance, respectively. Finally, V_s is sampling output voltage of the DC-DC converter. So, the boundary values and range of the input resistance R_i and measuring resistance R_m can be expressed as;

$$R_i \geq \frac{V_o}{i_i} = \frac{300V}{10mA} = 30kohm \quad (1)$$

$$R_m \geq \frac{V_{ADC,max}}{i_s} = \frac{3.3V}{25mA} = 132ohm \quad (2)$$

Where $V_{ADC,max}$ is maximum sampling voltage of ADC in the TMS320F28335. ADCs for DSP is limited to be 3.3V. Sampling voltage equation can be expressed as

$$V_{ADC} = \frac{V_o}{R_i} \cdot \frac{2500}{1000} \cdot R_m \quad (3)$$

For the closed loop control system, reference voltage V_{ref} is selected as 2.5V. So, one can say that equation of the reference voltage can be expressed as $V_{ref}=V_{ADC}$.

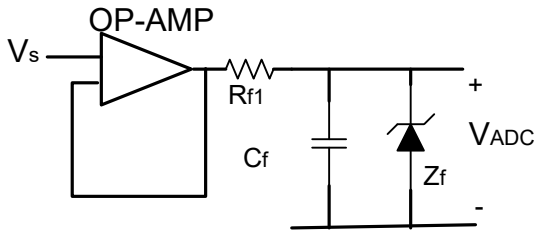


Figure 3. Signal conditioning circuit.

In Figure 3 the operational amplifier is configured as a buffer. This unity gain buffer protects the ADC of TMS320f28335. Zener diode Z_f was also used to protect against high voltage which may damage ADC component of TMS320f28335. In low pass filter (LPF) circuit, corner frequency of the LPF chosen ten times lower than the ADC sampling frequency meets the requirement to eliminate signal-path noise (Baker, 2015). So, if the ADC is converting at 100kHz, LPF corner frequency can be preferred as 10kHz. Therefore, corner frequency equation can be expressed as;

$$f_c = \frac{1}{2\pi \cdot R_{f1} \cdot C_f} = 10kHz \quad (4)$$

By using equation 1-4 and resistors and capacitors which are available in resistor and capacitor stock, the parameters of signal sampling circuit is calculated as in Table 1.

Table 1. The parameters and values of the signal sampling circuit.

Parameter	Value
Primary side current	$i_i=9.09mA$
Secondary side current	$i_s=22.73mA$
Output voltage of the converter	$V_o=300V$
Input resistance	$R_i=33kohm$
Measuring resistance	$R_m=159ohm$
Corner frequency	10kHz
Resistance of LPF	$R_{f1}=1.6kohm$
Capacitor of LPF	$C_f=10nF$

In this research, a digital signal processing (DSP) experimental kit TMS320F28335 was selected as the main controller module because it offers many advantages such as low cost, excellent convergence and ease of use. The control method applied to keep the output voltage of the double-stage boost converter at the desired level will be digital PI control. A digital signal processing (eZdsp TMS320F28335) development kit is used as controller (Guo, 2006). Transfer function of PI controller can be expressed as;

$$G_c(s) = K_p + \frac{K_I}{s} \quad (5)$$

For digital control, the PI controller transfer function must be converted from continuous time domain to discrete time domain. Therefore, the equivalent of the transfer function of the digital PI controller can be expressed as;

$$G_c(z) = K_p + \frac{K_I \cdot T_s \cdot z}{z - 1} \quad (6)$$

The transfer function of the digital PI controller is in the discrete time domain can be expressed as;

$$u[k] = K_p \cdot e[k] + K_I \cdot T_s \cdot \sum_{i=0}^k e[i] \quad (7)$$

and

$$e[k] = V_{ref} - V_{ADC}[k] \quad (8)$$

Here, $V_{ADC}[k]$ refers to the digital value of the k_{th} sample of the output voltage, and V_{Ref} refers to the digital value corresponding to the reference value of the desired output voltage.

3. Results and Discussion

Hardware circuit of the proposed system was realized after the design and the modelling. By testing this laboratory prototype, a series experiments are done to verify performance of the system. Configuration of the converter, driver, DSP and voltage sensor and signal conditioning circuit are illustrated as

Figure 1. Hardware prototype of the proposed system and voltage transducer can be observed in Figure 4 and Figure 5, respectively. LV 25-p voltage transducer from LEM, 33kohm input resistance, 159ohm measuring resistance were used as components of voltage transducer circuit. TL072 operational amplifier (OP-AMP), 3V regulated zener diode, 1,6 kohm filter resistance and 10nF filter capacitor were used as components of the signal conditioning circuit.

Traditional PI control as a control method was applied to regulate output voltage of the high step-up DC-DC converter by using TMS320F28335 eZdsp development kit. Figure 6, Figure 7 and Figure 8 show the experimental results of the PI control system which uses the sampling output voltage obtained via LV-25p voltage sensor.

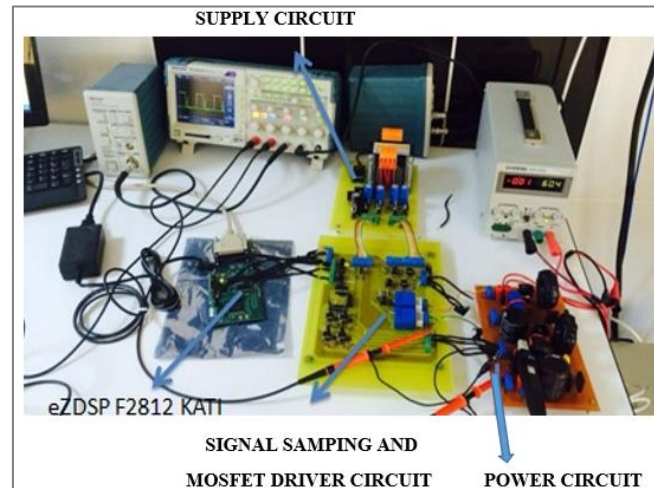


Figure 4. Hardware prototype on laboratory.

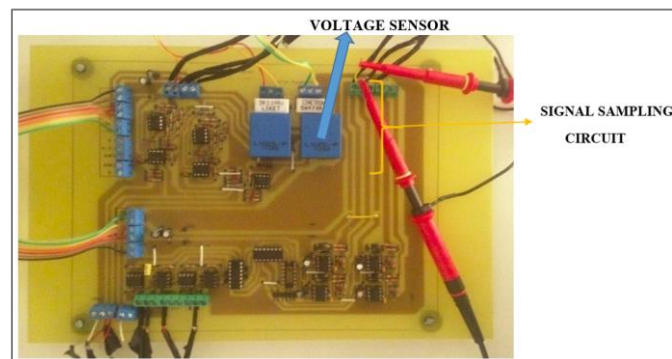


Figure 5. Hardware circuit of signal sampling.

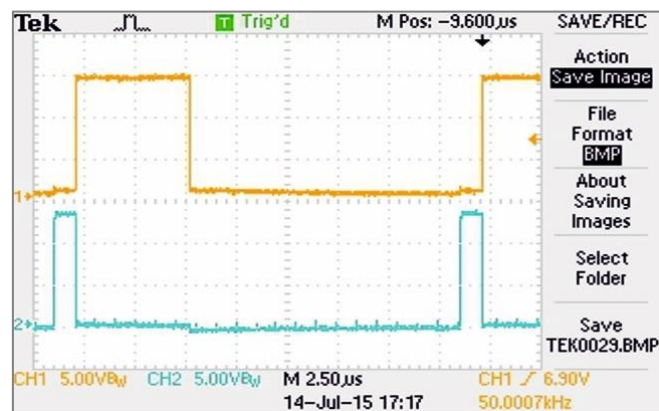


Figure 6. Gate PWM signal of the power switches (Genc & Koc, 2017).

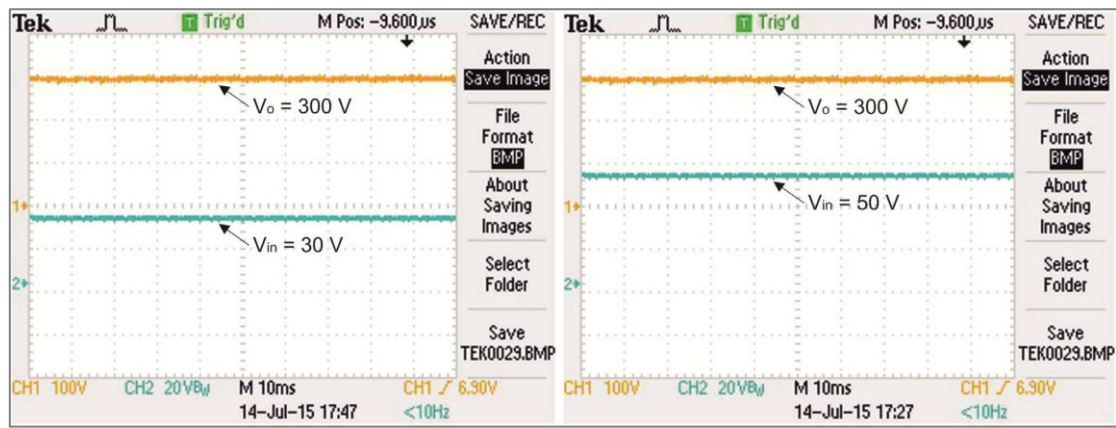


Figure 7. Output voltage of the converter regulated to 300V under different input voltages (Genc & Koc, 2017).

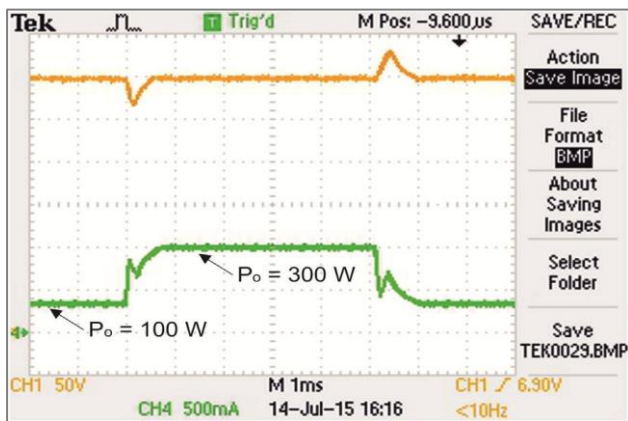


Figure 8. Transient response of the output voltage while changing the output power from 100W to 300W or from 300W to 100W (Genc & Koc, 2017).

Proposed converter system was operated for different input voltage and output power in order to show the performance of the DSP controller and voltage sensor. Figure 6 shows the control signals of the main switch M and auxiliary switch M_a of the converter, respectively. Figure 7 displays the output voltage of the converter under different values of input voltage of the converter. Firstly, when the input voltage was 30V, 300V output voltage was obtained under 300W output power by applying the gate signal to switches via DSP and powered drive circuit. Then, while input voltage was increased from 30V to 50V, output voltage maintained to be 300V. Additionally, to observe the transient response of output voltage under different loads, proposed system was tested. As can be seen in Figure 8, when output power was changed from 100W to 300W or vice versa, output voltage maintained to be 300V and a fast transient response was observed. These results obtained by using the voltage sensor LV 25-p, signal conditioning circuit and DSP controller kit shows that this output voltage regulation system has a reliable and robust performance.

4. Conclusion

A prototype of a measurement board aimed for the high step-up DC-DC converter system has been designed and modelled. Measuring of output voltage of the power system, monitoring by detecting electrical disturbance, transients and fluctuations and ensuring real-time data for controller is important in the power system. A well measurement board introduce to the power system a facility of the perfect accuracy and elimination the external interference. In this measurement board prototype, high quality voltage sensor ensures a precise result to the controller. So, voltage transducer LV 25-P from LEM have been met the significant requirements mentioned above. Thus, by using the designed and modelled measurement board, a good output voltage regulation of the proposed converter has been achieved. The output voltage maintained to be 300V when the different input voltages (from the 30V to 50V) and different output loads (from the 100W to 300W) were applied to converter.

Conflict of Interest

Author declares that he has no conflict of interest.

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