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# Arduino based pulse width modulated output voltage control of a dc-dc boost converter using Proportional, Integral and Derivative control strategy

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A B S T R A C T

PWM or Pulse Width Modulation based control of power electronic circuits is the most common method used for controlling the output voltage of boost converters. It involves changing the $t_{on}$ and $t_{off}$ duration of the MOSFET switch at a constant frequency. The paper deals with a controller based on PID control strategy. A low cost micro-controller board, Arduino ,has been used to implement the PWM control technique thus obviating the need for complex hardware circuitry . MATLAB-Simulink was used to design and tune the PID controller parameters as well as to make the Arduino microcontroller a stand-alone device.



## INTRODUCTION

Dc-dc boost converters are step-up converters whose output voltage is greater than the input voltage. These converters find use in hybrid-electric vehicles and lighting systems. The major disadvantage of open loop converters is that on changing the load in the circuit the average output voltage changes. To control the fluctuations in the output voltage due to load change a control scheme is needed (Christian Kranz,2003). Arduino micro-controllers are low cost, easy to use controllers which are able to read analog values and provide PWM outputs accordingly. MATLAB-Arduino interface can be used for coding the controller using a Simulink model thus making it a stand-alone device which receives inputs and provides outputs accordingly. The coded controller is then directly used in continuous control of the output voltage.

## MATERIALS AND METHOD

### *Arduino:*

Arduino is a microcontroller board based on the ATmega328 microcontroller. ATmega328 is a low power 8-bit controller by AVR. It has an in-system; self-programmable, flash program memory of 32kBytes. 0.5 kB of this memory is used up by the Arduino boot loader program. It also has an in-built 10 bit ADC which makes it possible for the user to read analog inputs directly. Apart from the microcontroller the board has 14 digital input/output pins out of which 6 can be give PWM outputs (used as analog outputs), 6 analog input pins, a 16 MHz oscillator, an ICSP header, and an ATmeg16U2 chip which acts as a USB to serial converter. The board can be powered through the USB cable or an AC-to-DC adapter or a battery (6-20V).

### *Arduino MATLAB Interface:*

We have used the Simulink Support Package for Arduino Uno Hardware (R2012a) for communicating between MATLAB and Arduino. A library of Simulink Blocks is provided by the support package which allows access to Arduino I/O pins and Serial Port. The package allows implementation of Simulink Models in Arduino board such that the board acts as stand-alone hardware.

### *Boost Conveter:*

A step-up or boost converter steps up the voltage supplied to it. When the switch is on, the output stage is isolated due to the diode's reverse biased condition. The input now supplies energy only to the inductor. When the switch is turned off, energy to the inductor is supplied by both- the inductor as well as the input supply(Muhammad H. Rshid, 2004).

$$V_d \times t_{on} + (V_d - V_{out})t_{off} = 0 \quad (1)$$

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Dividing both sides by $t_s$ and rearranging terms yield

$$\frac{V_{out}}{V_d} = \frac{1}{1\text{-}D} \tag{2}$$

Where
$V_{out}$=output voltage;
$V_d$=input voltage;
D=converter duty ratio

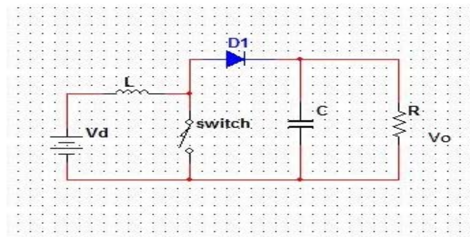


**Fig. 1:** DC-DC boost converter

***Circuit Description:***

The input and output voltages for the boost converter were fixed as 12V and 24 V respectively. Our power output was fixed at 192mW. Since we have used an Arduino PWM output for gating the MOSFET gate, the switching frequency was 500Hz, thus $T_s$= 2ms (Ned Mohan, 2002) . The switch used in the circuit was IRFZ44N N-channel enhancement mode MOS transistor .

According to the design constraints the maximum output current was calculated to be $I_{omax}$=8mA.Assuming the capacitance value as very large, we took C=1000µF.

The value of D=0.5.

The maximum value of the inductor L can be calculated as

$$L = T_s \times V_{out} \times \frac{D(1-D)^2}{2 \times I_{out}} \tag{3}$$

$$= \frac{24 \times 2 \times 10^{-3}}{2 \times 8 \times 10^{-3}} 0.5(1-0.5)^2$$

$$L = 150\text{mH} \tag{4}$$

The main reason for having low current values was using a decade inductance box (DIB) for our inductor value. The maximum current than can be handled by the DIB is 200mA. An attenuator circuit, a π- connected resistor network was used for feeding the output voltage into the Arduino.

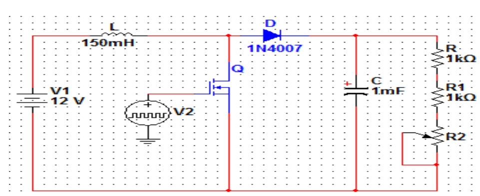


**Fig. 2:** Circuit used for the hardware model

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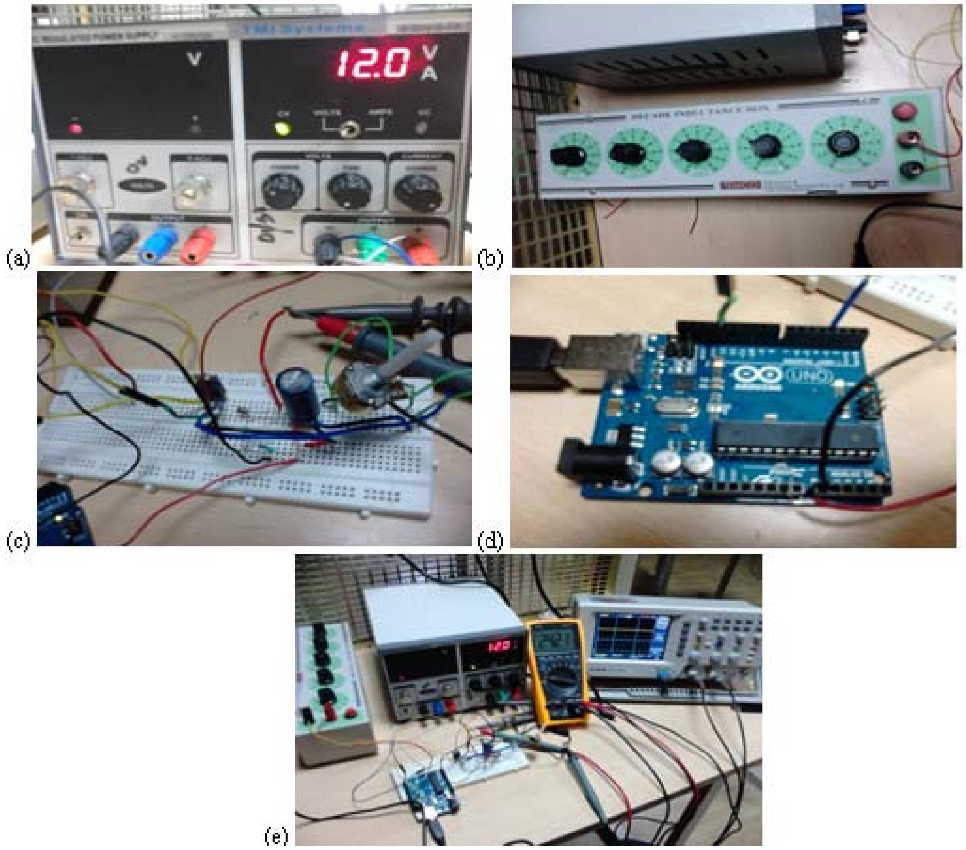



**Fig. 3:** Hardware components used; (a) DC power sourc, (b) Inductance box, (c) Boost-converter circuit (d) PWM wave generating Arduino UNO micro-controller, (e) Complete hardware setup

***Control Strategy:***

Our aim was to keep the output voltage of our boost converter constant(A. Mohamed,2010). We used a simple P controller to achieve this(John Sandoval,2010 and R. De Keyser,2010). The output voltage of the converter can be controlled by the PWM signal given to the gate. As explained, the duty cycle of this signal influences $V_{out}$. The duty cycle can in turn be controlled by a PID controller(H. Sira-Ramirez,1990). In the controller, the output voltage across the load is given as feedback and compared with a set point. The error is then multiplied with the proportional gain and given as analog input for PWM. We took advantage of the fact that the Arduino Board can give direct PWM outputs; hence we could avoid the use of separate PWM generators. Since at zero error, the PWM should have 0.5 duty cycle (as per calculations), this offset was added to the controller output.

The analog input pin of the UNO board can have a maximum value of 7-12V. To be on a safer side we limited our input values within 5V. This meant that $V_{out}$ could not be fed back to the controller directly. That is why we used an attenuator circuit, a π-network of three 1kΩ resistors which gives a feedback voltage proportional to output voltage but within the range. At 24 V the feedback voltage was 5V hence we choose our set point to be 5V. We chose the gain parameter of our controller to be 100.

The 10-bit ADC converts the input voltage into a digital value between 0-1023; this value needs to be scaled down by a proper factor (1/1024) to give the actual digital value. Similarly the PWM pin on the board gives an output of duty cycle 0.0 for an input of 0 and duty cycle 1 for the input 255. Hence for a duty cycle of 0.5, the value of 127.5 is used as the input.

Thus, when the output voltage changes the duty cycle is changed by the P controller so as to keep the output voltage constant. The voltage from the π-network was fed into the Analog Pin0 of the board and the PWM pulses were generated form the Pin3 and fed into the gate terminal of the IRFZ44N transistor.

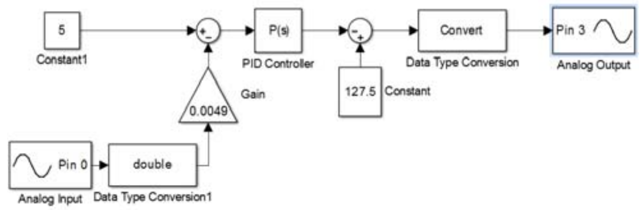
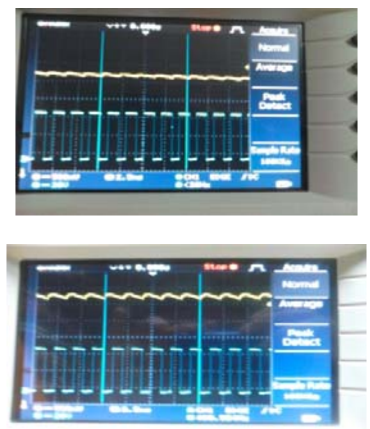



**Fig. 4:** Simulink model of the control strategy (This model is burnt into the micro-controller)

***Results:***

When the Boost converter was operated in open loop, the output fluctuated between 20V and 50V while varying the resistive load from 2kΩ to 470k. When the same setup was operated in a closed loop with a P controller, the voltage remained constant at 24V.

Furthermore we tested the effectiveness of our filter circuit by selecting two different values for the capacitor. We observed that the peak-to-peak voltage was 75 mV for a 1000µF, and 200mV for 470µF.



(a)

(b)

**Fig. 5:** Output along with the PWM pulse;(a) Output Waveform in the CRO with 100pµF Capacitor,(b)Output with 470µF Capacitor

***Conclusion:***

An Arduino based controller is easy to program and when used along with Simulink, the model can be directly burnt into the micro-controller board. Data acquisition and implementation through the arduino board is made easy by the analog input pins. The controller itself does not incorporate more hardware components as used in many op-amp based PID controllers and thus is less bulky and easy to handle.

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