**IJCTA**, 9(16), 2016, pp. 8043-8049


# Digital Real-Time IP controller for Buck Converter

**K. Sharmila Devi*, J. Vijay Prabhu** and P. Blessy Hepsiba*****

**ABSTRACT**

The switched-mode dc-dc converters is one of the most widely used power electronics circuits for its high conversion efficiency and flexible output voltage. Closed loop control strategy is indispensable in power converters to meet the desired load requirements. The proposed system employs a closed double loop IP controller for load regulation and line regulation of dc-dc buck converter. IP controller has proportional gain in feedback path and Integral gain in forward path, which enhances system dynamic response and reduces undesirable peak overshoot compared to conventional PI controller. IP controller also reduces system's sensitivity to parameter variations which results better transient response of the system.

***Keywords:*** Buck Converter, IP controller;

## 1. INTRODUCTION

DC-DC converters find many applications in areas like Hybrid electric vehicle, LCD Backlight etc .Closed loop control circuits are generally employed along with converters for better performance both under transient and steady state conditions .Converters require control arrangement with feedback loop to meet the desired requirements, accurate tracking, fast response and high precision.The conventional controllers are an option where simplicity in the control can be achieved.This controller has both propotional and integral gain in the forward path as shown in the Figure 1.

On the other hand PI controller has some disadvantages: undesirable peak overshoot,sluggish response to changes and sensitivity to contoller gains $K\text{-}_i$ and $K_p$.

To overcome the above stated disadvantages the controller is modified to form new configuration named IP controller. IP controller is a dual loop closed loop control strategy.The configuration of the IP controller can be seen in Figure 2.

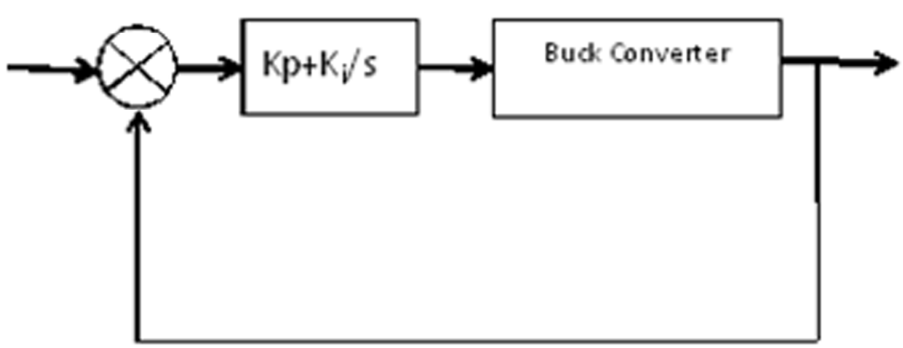


**Figure 1: DC-DC converter PI configuration.**

* Assistant Professor, Department of EEE, SRM University, Chennai, *Email: info2sj@gmail.com*

** Assistant Professor, Department of EEE, SRM University, Chennai, *Email: vijayprabhuj@gmail.com*

*** Assistant Professor Department of EEE, SRM University, Chennai, *Email: blessyhepsiba@yahoo.co.in*

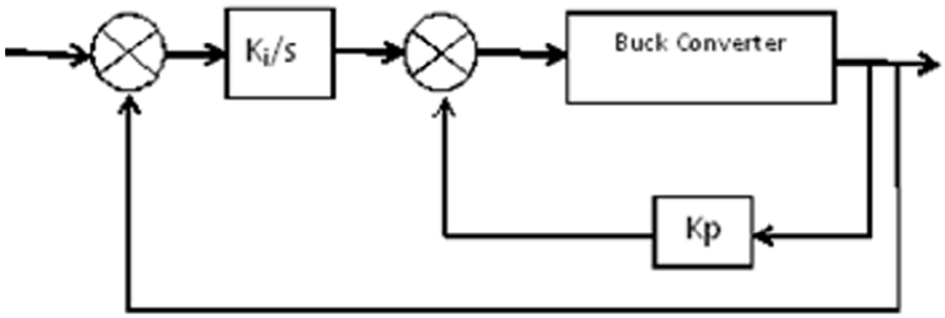


**Figure 2: DC-DC Buck converter with IP controller**

In IP controller Integral gain ($K_i$) is placed in the feed forward path, whereas Proportional gain ($K_p$) is in the feedback path.The use of IP controller enhances system dynamic response and reduces undesirable peak overshoot.IP controller does not introduce any zero to the system and thus overshoot can be reduced to a great extent when compared to the conventional PI controller. Also IP controller is inherently adaptive in nature.

In this paper the performance of PI and IP controller are compared using MATLAB and the same are reported.In addition hardware implementation of IP controlled DC-DC Buck Converter using Texas Instruments F28027 is presented.

## 2. ANALYSIS AND DESIGN

The electronic circuit of the Buck converter is shown in Figure 3 .It is assumed that the semi-conductors are ideal, i.e., the transistor *Q* has an infinitely fast response while the diode *D* has a threshold value equal to zero. This allows that the conduction state and the blocking states are activated with no loss of time whatsoever.

In order to design a buck converter it is of most importance to decide the values of the components used .The components are selected properly so as to get the desired output.

The fundamental property of an inductor is to oppose the change in the magnitude of current passing through it. In buck converter the switching action of MOSFET is done at very high speed. Hence switch produces discontinuous output current, but it is the inductor, which overcome this problem.

Selection of the inductor is done by using the following formula (1):

$$L = (V_{IN} - V_{OUT}) \times \left(\frac{V_{OUT}}{V_{IN}}\right) \times \left(\frac{1}{f_{sw}}\right) \times \left(\frac{1}{0.4 \times I_{OUT}}\right) \quad (1)$$

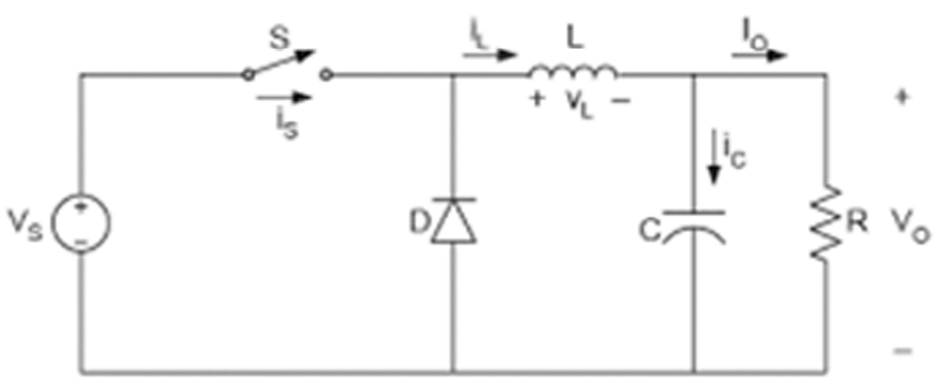


**Figure 3: Electronic circuit of dc-dc buck converter**

Where,

$L$ = Value of Inductor,

$V_{IN}$ = Input DC voltage to Buck converter,

$V_{OUT}$ = Desired output DC voltage,

$f_{SW}$ = Switching frequency of MOSFET,

$I_{OUT}$ = Output current.

The main function of capacitor is to maintain constant output voltage.it makes the output voltage ripple free. As ideal capacitor is almost practically impossible to construct there always an ESR incorporated with it and this ESR affects the output voltage. The best practice is to use low-ESR capacitors to minimize the ripple on the output voltage.

In order to achieve better output voltage regulation, low-ESR capacitors are required. Ceramic capacitors generally have very low ESR.

The value of capacitor C is chosen by (2):

$$C = \frac{\Delta I_L}{\Delta V_{OUT} \times 0.8 \times f_{sw}} \tag{2}$$

Where,

$C$ = Value of Capacitor,

$\Delta I_L$ = Estimated Inductor ripple current,

$\Delta V_{OUT}$ = Output voltage ripple,

$f_{SW}$ = Switching frequency of MOSFET.

And,

$$\Delta_{I_L} = 0.4 \times I_{OUT} \tag{3}$$

For the employed system the diode is designed based on the average power rating of the diode. Average power rating can be calculated as (4):

$$P_{DIODE} = \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times I_{OUTMAX} \times V_D \tag{4}$$

Where,

$P_{DIODE}$ = Average Power across Diode,

$I_{OUTMAX}$ = Maximum Output current,

$V_D$ = Voltage across Diode.

For the proposed system MOSFET named IRF540n is employed. As it is having fast switching, dynamic $\frac{dV}{dt}$ rating, low on resistance, high operating temperature, full avalanche rating.

The parameter values for DC-DC buck converter for which input voltage is 24v and output voltage is bucked to 12v is calculated and tabulated in Table 1.

**Table 1**
**Parameters of buck converter**

| *Symbol* | *Parameter* | *Value* | *Units* |
|---|---|---|---|
| R | Load Resistance | 100 | Ω |
| L | Series Inductance | 3 | mH |
| $R_L$ | Estimate Series Resistance (ESR) of Inductor | 10 | mΩ |
| C | Capacitance | 47 | μF |
| $R_C$ | ESR of Capacitor | 30 | mΩ |
| Vin | Input Voltage | 24 | V |
| Vout | Output Voltage | 12 | V |

The transfer function of the buck converter (5) is derived by the standard state-space averaging technique.

$$\frac{v_0(s)}{d(s)} = \frac{V_I \times R}{s^2 LCR + sL + R} \tag{5}$$

Where,

$V_I$ = Input buck converter voltage,

$L$ = Inductor value,

$C$ = Capacitor value,

$R$ = Resistor value.

## 3. SIMULATION

Parameters of a prototype buck converter are listed in Table I. Then the ideal model (without parasitic elements) of the converter can be derived as (6):

$$\frac{v_0(s)}{d(s)} = \frac{100}{s^2 + 33s + 100} \tag{6}$$

By using this model simulations of buck converter is performed on MATLAB SIMULINK. The results of these simulations are presented in Table 2. In Figure 6 output of buck converter using IP and PI controller are presented. The proportional ($K_p$) and integral ($K_i$) gain used are 0 and 35.

**Table 2**
**Comparision of performance between PI &IP**

| *Control Parameter* | *IP* | *PI* |
|---|---|---|
| Rise Time(ms) | 0.54 | 0.50 |
| Settling Time(ms) | 5.3 | 5.0 |
| Over shoot(%) | 18.6 | 41.27 |
| Peak (v) | 14.23 | 16.95 |
| Peak Time(ms) | 1.2 | 1.2 |

From the Figure 4 it is clear that IP controller outperformed traditional PI controller in terms of reducing the peak over shoot and decreasing the rise which improves the response of the system. When IP controller is used the system reaches the set point in 5.3ms, while it takes 6ms Of settling time when implemented using PI controller.

For the above modeled buck converter load regulation is performed and results are presented in Figure 5.

In the Figure 5 simulation, the load resistance of buck converter is varied from 5ohm to 15ohm. As the output resistance increases there is no change in the output voltage of the buck converter this shows the load regulation of the designed multi loop IP controlled dc-dc buck converter.

In addition to the load regulation the buck converter should also have line regulation . It is a characteristic in which the input voltage varies but the output voltage does not vary. This is very essential for proper functioning of dc-dc buck converter.Simulation report of Line regulation is presented in the Figure 6.

While performing load regulation the input voltage is varied from 18v to 30v.Though,the input voltage is varied the output voltage is constantly at 12v.This ensures line regulation of the multi loop IP controlled dc-dc Buck converter.

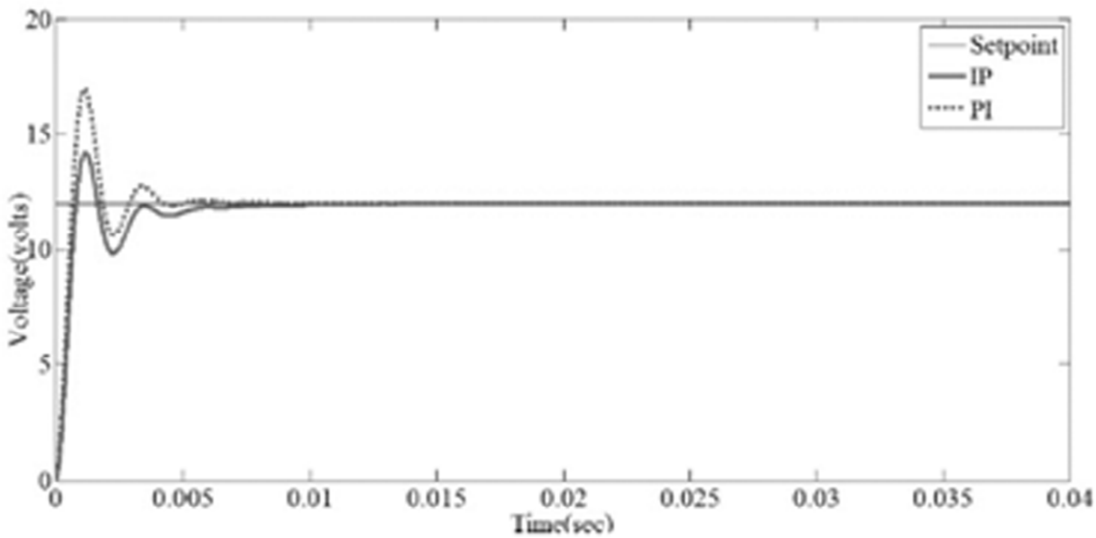


**Figure 4: Simulation of output voltage using IP & PI controller**

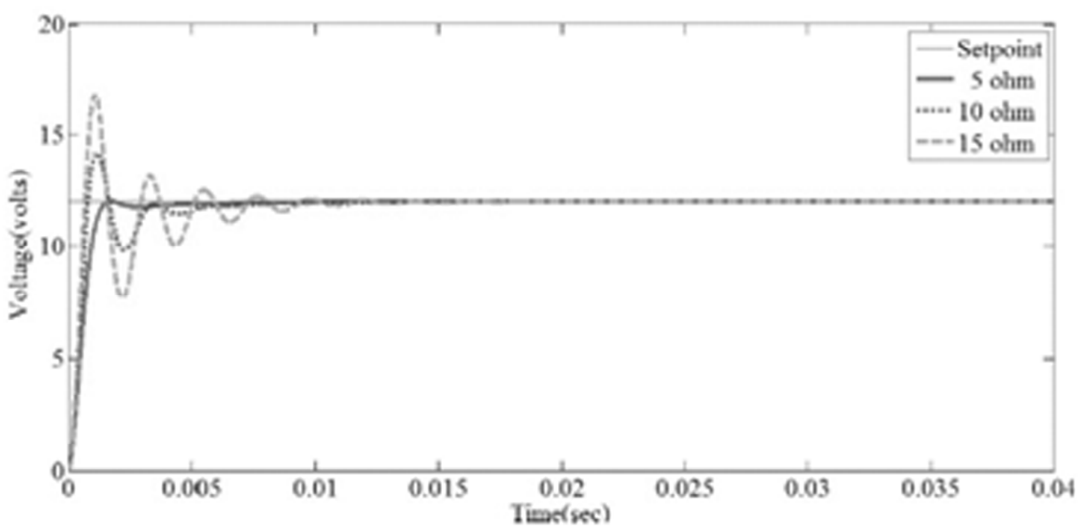


**Figure 5: Load regulation of dc-dc Buck converter**

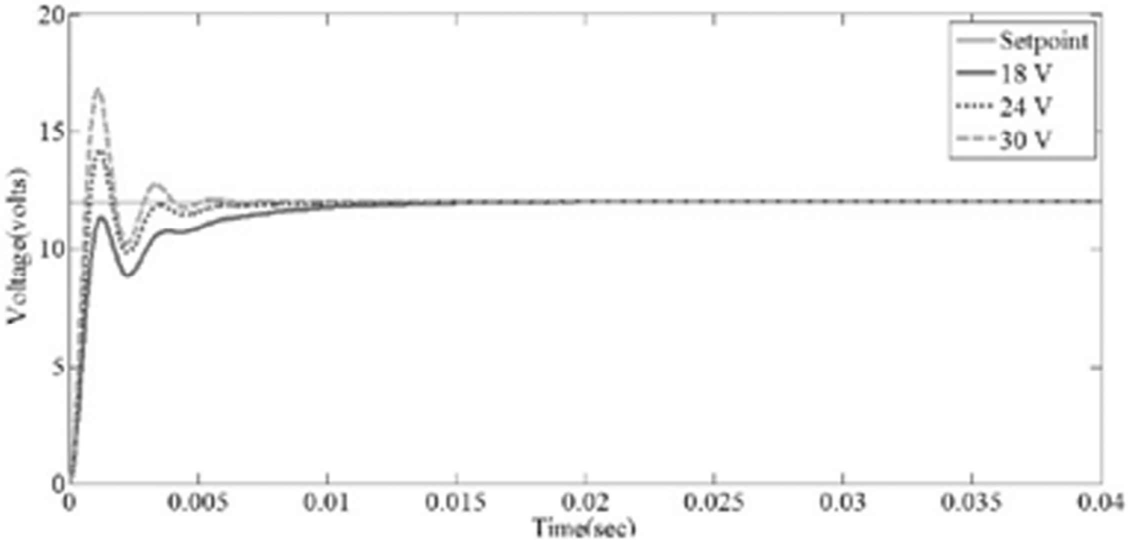


**Figure 6: Line regulation of dc-dc Buck converter**

## 4. HARDWARE

All the components of the system can be briefly classified into four modules. They are Power supply module, Gate driver module, Buck converter module and Processor module.

Power supply module is amalgamation of different power supply units which are needed for the functioning of the dc dc buck converter. There are three power supply units in total. Two out of the three power supply units are employed for providing bias voltage for the functioning of the gate driver circuit. The other supply unit is used for the purpose of providing dc voltage input to the buck converter.

Power supply unit carries out the function of taking 230v AC supply as input and producing dc voltages of magnitudes 5v, 12v and 20-30v.

The next module is Gate driver module. A gate driver is a power amplifier that accepts a low-power input from a controller IC and produces a high-current drive input for the gate of a high-power transistor such as a power MOSFET. Gate drivers can be provided either on-chip or as a discrete module. The gate driver used in the proposed system is IR2110,having exemplifying features that suits the system.

IR 2110 is a Gate driver IC to which two power supplies 5v,12v are given to pins 9 and 3 respectively. The PWM pulse from controller ie piccolo F28027 which has to be amplified is given to pin 12.Then,amplified output which has to be given to MOSFET IRF540n is taken from pin1.

Based on the values in the Table1 the buck converter is designed. This is the main buck converter module with capacitor of capacitance 47$\mu F$, Inductor of inductance 3mH.

The C2000 Piccolo LAUNCHXL-F28027 launch pad is employed for the proposed system. The controller has jumper sections from J1-J6 where J2 and J6 are used for PWM, where J1 and J5 are for feedback to controller.

Piccolo F28027 is used to generate PWM waveform and uses a close loop IP strategy which is stored in the processor to produce control output. To achieve this the output of the Buck converter is fed to the processor.

Opto coupler MCT2E is used for isolation of buck converter output and this output is used to give feedback to the piccolo F28027.

Now, all these four modules are united to form the double loop IP controlled DC-DC Buck converter which is shown in Figure 7.

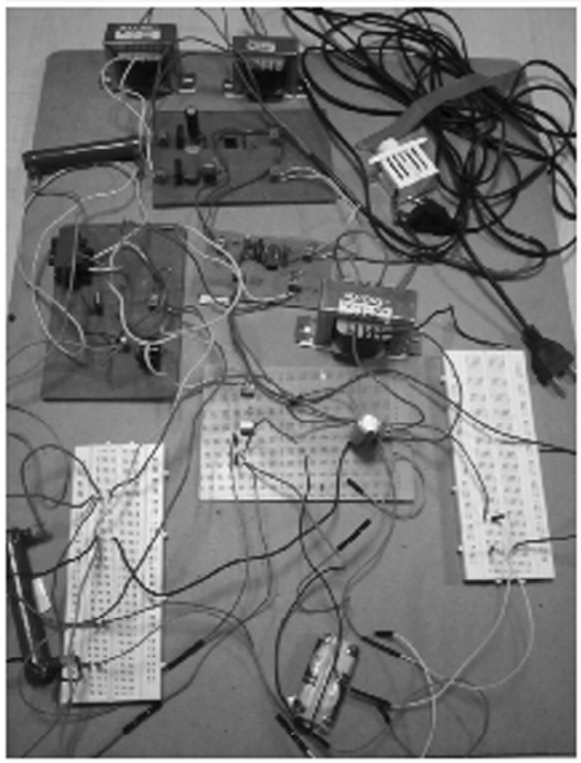

**Figure 7. Real time Double loop IP control Buck converter**

## 5. CONCLUSION

The analysis, design ,load regulation and line regulation of DC-DC Buck converter operated in continuous using IP controller has been successfully demonstrated through the MATLAB/Simulink simulation and Hardware demonstration is presented in this paper. The control technique uses a double loop IP controller to reduce the undesired peak overshoot and to improve the transient and steady state response of DC-DC Buck converter.Comparision between PI and IP controller controlled DC-DC Buck converter is performed and results are presented with hardware validation.

## REFERENCES

[ 1] F. I. Ahmed, A. M. EI-Tobshy, A. A. Mahfouz, and M. M. S . Ibrahim, “P-I and I-P Controllers In A Closed Loop For DC Motor Drives,” Power Conversion Conference - Nagaoka 1997.

[2] Sreekumar T, and Jiji K S, “Comparison of Proportional-Integral (P-I) and Integral-Proportional (l-P) controllers for speed control in Vector controlled Induction Motor Drive,” International Conference on Power, Control and Embedded Systems 2012"

[3] Deepika Vasanthakumar, Srikanth Vasudevan Pillai “DC-DC Converter Control using IP Controller,” International Conference on Computation of Power,Energy, Information and Communication, 2014.

[4] U. Nagrath and M.Gopal, “Control System Engineering,” New Age International (P) Limited.

[5] Benjamin C. Kuo and Farid Golnaraghi, “Automatic Control Systems,” Prentice-Hall Inc.

[6] Xie Dongmei,Qu Daokui, Xu Fang, “Design of feedback controller and IP position controller of PMSM servosystem” lEEE international conference on Mechatronics and Automation Niagra Falls, Canada, July 2005.

[7] Lin Faa-Jeng, “Real-time IP Position controller design with torque feedforward for PM synchronous motor,” iEEE Trans. On industrial Electronics, Vo1. 44, No. 3, pp. 398, 407, 1997.

[8] Daniel.W. Hart, “Power Electronics,” McGrawHill, 2010, pp. 198-206.

[9] Robert W. Erickson, Dragon Maksimovie, “Fundamentals of Power electronics second edition” Springer International Edition.